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# RADIOLOGICAL IMPACTS OF JACKPILE-PAGUATE URANIUM MINES

## An Analysis of Alternatives of Decommissioning

by


M. H. Momeni, S. Y. H. Tsai, J. Y. Yang,
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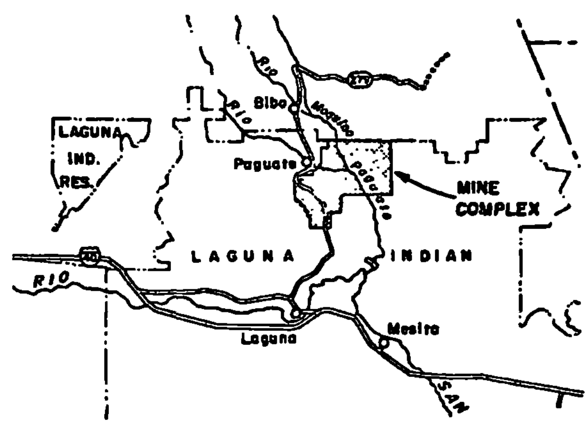



ARGONNE NATIONAL LABORATORY, ARGONNE, ILLINOIS

Operated for the U. S. DEPARTMENT OF ENERGY
under Contract W-31-109-Eng-38

Printed in the United States of America
Available from
National Technical Information Service
U. S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161

NTIS price codes
Printed copy: A11
Microfiche copy: A01

ARGONNE NATIONAL LABORATORY
9700 South Cass Avenue
Argonne, Illinois 60439

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Bureau of Land Management
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March 1983

Prepared for

Bureau of Land Management and
Bureau of Indian Affairs
U.S. Department of the Interior

Under Letter of Agreement Dated August 6, 1981
(Requisition 2-6035-04351)

 

## FOREWORD

This radiological impact analysis of alternatives for the decommissioning and reclamation of the Jackpile-Paguate Uranium Mines in Cibola County, New Mexico, was prepared for the U.S Department of the Interior (DOI), Bureau of Land Management, South Central Region, Albuquerque, New Mexico, and the U.S. Bureau of Indian Affairs. This report is intended to be a support document for the environmental impact statement being prepared by the U.S. Department of the Interior on the Anaconda Minerals Company's proposal to reclaim the Jackpile-Paguate mines.

Radiation doses from atmospheric transport and ingestion of radionuclides were calculated, and somatic and genetic effects in individuals living within 80 kilometers (50 miles) from the mine complex were predicted. The analyses are for periods after completion of five separate alternatives of decommissioning. In addition, hydrological flow patterns in the mine area were analyzed to determine the potential for future contamination of surface water and groundwater and to determine the groundwater recovery level after reclamation, thus permitting incorporation of corrective actions into the reclamation procedures.

The authors wish to acknowledge the contributions of M. Nelson (Bureau of Land Management) and B. Zehner (U.S. Geological Survey) to this report. Also, the authors are indebted to D. Connor, A. Gudat, C.J. Roberts, and Y. Yuan (ANL) for technical review, and to J.D. DePue (ANL) for the preparation of the document.

This work was prepared under a letter of agreement from the U.S. Department of the Interior dated August 6, 1981 (Requisition 2-6035-04351).

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## SUMMARY

Although mining activity at the Jackpile-Paguate Uranium Mines in Cibola County, New Mexico, has stopped, humans continue to be exposed to the radioactive materials remaining on the mine site. The magnitude of future exposure from these sources will depend upon the degree to which the reclamation procedures that are implemented will prevent release of radioactivity into the principal pathways of migration--the atmosphere and the hydrosphere.

Potential pathways of radiation exposure and radiation-induced genetic and somatic effects from materials at the mine complex under five alternatives of decommissioning were analyzed using UDAD and PRIM computer codes. The principal pathways of exposure included in the analysis were inhalation of airborne radionuclides, ingestion of food and water containing radionuclides, and extended exposure to gamma and beta radiation from either airborne or ground-deposited radionuclides.

The alternatives of decommissioning include (A) No Action (site will be fenced, otherwise left as it is), (B) No Future Use (site will be fenced and all disturbed area will be covered with 30 cm of soil, no grazing on the site); (C1) Grazing Land Use as developed by Anaconda Company (protore, waste piles, and open pits covered with 120 cm of soil, the remainder of the disturbed areas covered with 30 cm of soil, pits backfilled 90 cm above the equilibrium groundwater recovery level, no human habitation or farming allowed on the mine site, but grazing would be allowed); (C2) Grazing Land Use as developed by U.S. Department of the Interior (similar to Alternative C1, but the pits covered with 300 cm of soil above the groundwater recovery level); and (D) Maximum Future Use (similar to Alternative C2, except construction of commercial and industrial facilities, storage, recreation, and further mining would be allowed).

The analysis of the atmospheric pathways of expoure for each of the above decommssioning alternatives included characterization of the sources of atmospheric release, estimation of the rates of release of the radionuclides, and calculation of airborne concentrations and surface activities of the radionuclides. The predicted airborne concentrations of all radionuclides at the mine boundaries under Alternative A (No Action Case) are less than the regulatory limits for airborne radionuclides. The magnitude of particulate releases was predicted to decrease to levels comparable to those of the natural environment of the mine site for Alternatives B through D. Relative to the Alternative A, the rates of release or radon were projected to decrease to 58% under Alternative B and to about 8% for Alternatives C1 through D.

The principal hydrologic pathways of potential radiation exposure in the vicinity of the mines are direct ingestion of contaminated water and, indirectly, ingestion of meat from livestock that drink contaminated water. The analysis of the hydrospheric exposure pathway indicated that this pathway would not

result in a predictable human exposure under any of the decommissioning alternatives. The groundwater supplies of the nearby town of Laguna most likely would not be affected within at least the next 100 years, irrespective of the decommissioning alternative implemented.

The dose rates and doses to individuals, the dose commitments to individuals and populations, and the environmental dose commitments for the atmospheric pathway were calculated for all towns within 80 km individually or as part of a larger urban area. The analysis indicated that exposures from radionuclides released from the mine site under Alternatives B through D would be negligible except for radon daughters. Under the Alternative B, the dose rate and doses to bronchial epithelium from radon would be 59% of the exposure under Alternative A; the exposures under Alternatives C1-D would be 8% of those for Alternative A.

The toal dose commitment from all pathways of exposure would exceed 25 mrem/yr for Alternative A (No Action Case), but would not exceed this limit for the other alternatives.

The potential radiation-induced genetic effects from all pathways of exposure would be about $3 \times 10^{-4}$ of those naturally induced genetic disorders. Similarly, relative to spontaneous cancer mortality, the total death from radiation-induced cancers (somatic effects) would be about $2.5 \times 10^{-4}$ and $7.8 \times 10^{-4}$, respectively, calculated using absolute and relative risk models. The primary type of radiation-induced cancer death is predicted to be from leukemia (68 out of 95 deaths in 85 years) using the absolute risk model, and from cancer of urinary organs and sex organs (137 cancers out of a total of 243) using the relative risk model. Even though the predicted contribution of lung cancer is only 0.9 death based on the absolute risk model, it is projected to produce 46 deaths under the relative risk model. The magnitude of uncertainty in these calculations is not less than ±2.5 times for dose estimates and not less than ±5 times for the risk calculations.

# 1. INTRODUCTION

## 1.1 OBJECTIVES

The Jackpile-Paguate mine complex is located on the Laguna Indian Reservation about 60 km (40 miles) west of Albuquerque, New Mexico, on about 3000 hectares (7500 acres) of land leased by the Anaconda Minerals Company (Anaconda) from the Pueblo of Laguna Native Americans. A map of the area is shown in Figure 1.1, and views of the mine complex are shown in Figures 1.2 through 1.4. The Jackpile ore deposits were discovered in November 1951, and the adjacent ore body, the Paguate, was discovered in 1956. Mining began in 1953 and continued until 1982. During that period, about 400 million metric tons of material were relocated within the mine area, and about 25 million metric tons of ore were recovered. Anaconda has submitted a reclamation plan for the mine complex to the U.S. Department of the Interior, Albuquerque, New Mexico. An analysis of pathways of radiation exposure and resultant health impacts from the decommissioned mines under Anaconda's proposed reclamation plan and four additional alternatives developed by the Department of Interior (DOI) is presented in this document.

One of the potential human health hazards associated with uranium-mine wastes is exposure to the radionuclides in the uranium-238 (U-238) series. The mine wastes include subgrade ores (protore)* with uranium contents that are too low to be economically recoverable under current conditions, but yet still emit radiation in excess of natural background levels. Because they currently cannot be economically milled, the protores are left at the mine site. At present, such mine wastes have a uranium content of less than 0.057%, i.e., a specific activity of less than 157.6 picocuries of U-238 per gram (pCi/g) of material. At the Jackpile-Paguate mines, analysis of radioactivity in composite samples indicates that other waste materials, such as overburden, are not mineralized. The concentrations of radioactivity in these materials are comparable to those in soils in the adjacent environment.

The radionuclides of concern are those in the uranium series, specifically uranium (U-238, U-234), thorium (Th-230), radium (Ra-226), radon (Rn-222),

---

*Traditionally protore was defined as materials containing concentrations of uranium ($U_3O_8$) between 0.02% and 0.039%, and ore as materials containing concentrations exceeding 0.04% $U_3O_8$. Because of improved technology for extraction of uranium, these definitions no longer apply. In this document all materials containing $U_3O_8$ in excess of 0.02% are classified as protore (radioactive mine wastes), and materials containing radioactivity in excess of 5 pCi/g for each of the radionuclides in the uranium series are classed as radioactive material (or mineralized material).

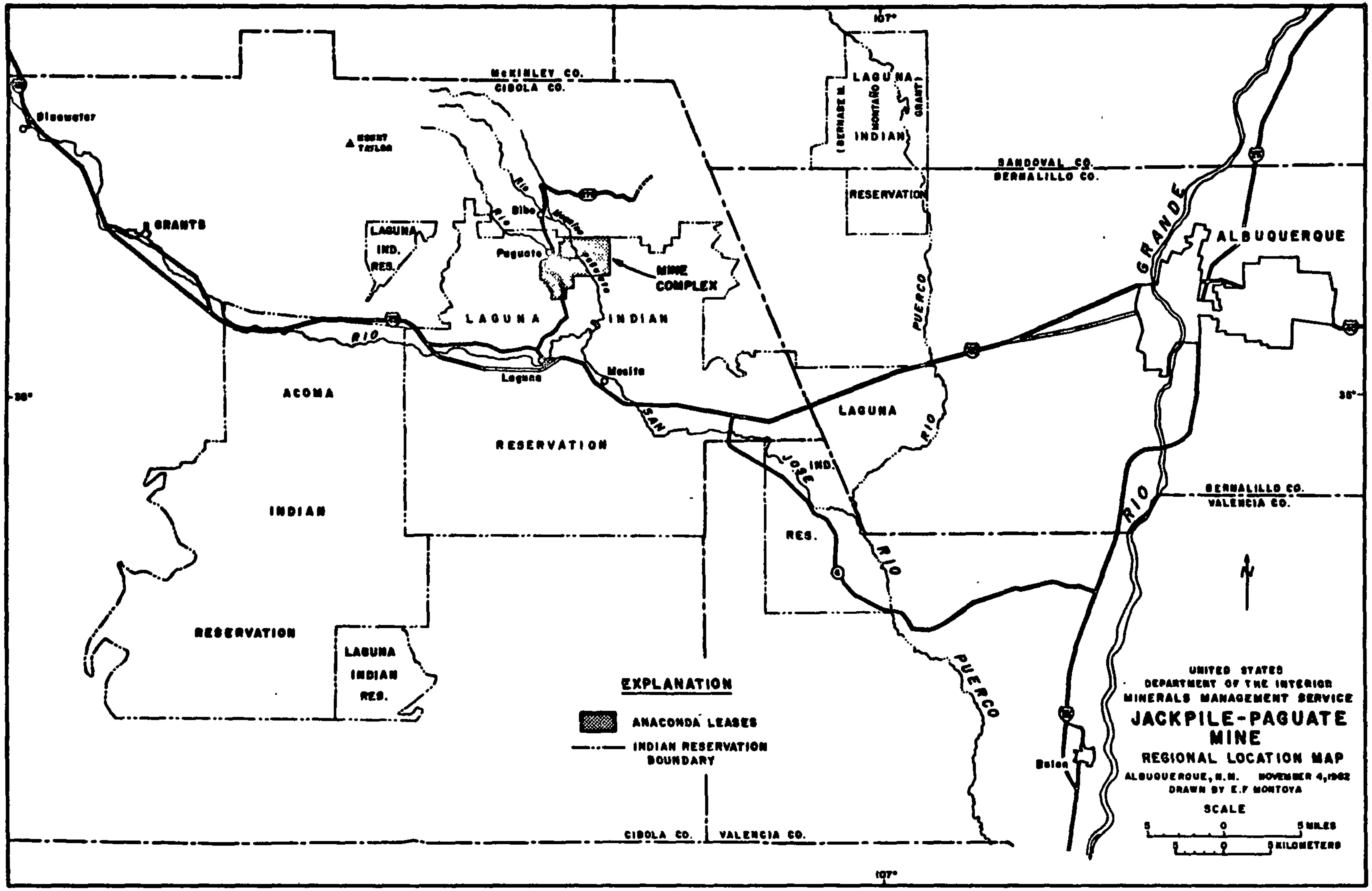



Figure 1.1. Map Showing Region Around Anaconda Company's Jackpile-Paguate Uranium Mine Complex.

Figure 1.2. View of the Mine Complex from Gavilan Mesa Looking West.

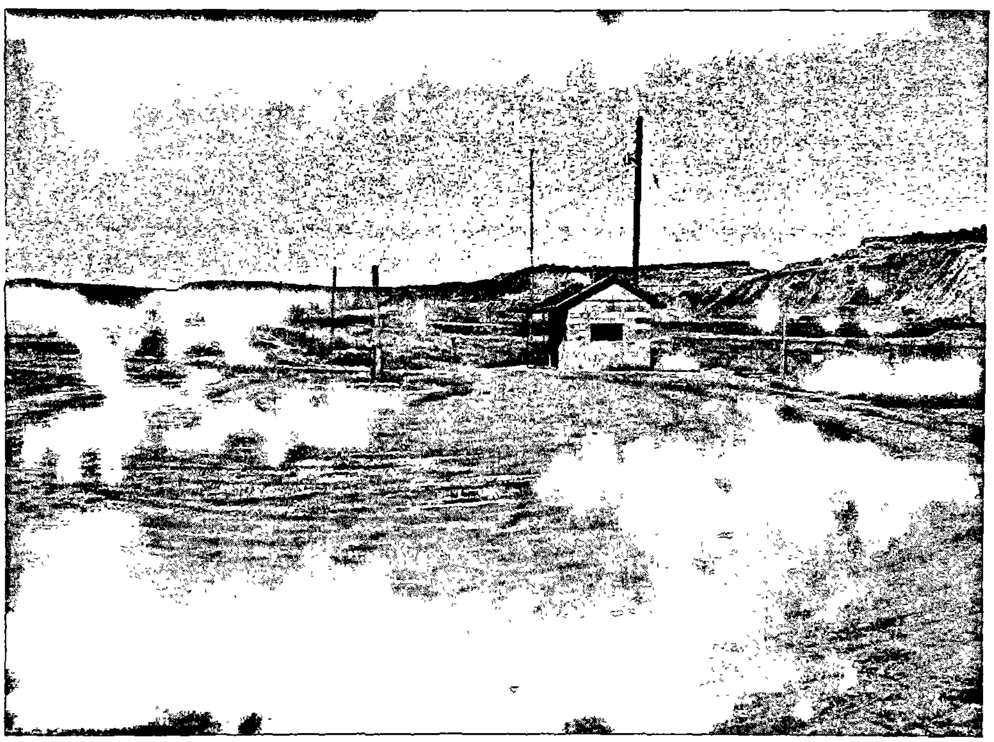


Figure 1.3. Site Entrance on the Southern Boundary of the Mine Complex.

Figure 1.4. Site Entrance on the Western Boundary of the Mine Complex.

polonium (Po-210), and lead (Pb-210). Potential sources of radiation exposure are fugitive dust, atmospheric release of Rn-222, and contamination of surface and groundwater with mine waste materials. The principal pathways of exposure are from inhalation of airborne radionuclides, ingestion of food and water containing the radionuclides, and extended exposure to gamma and beta radiation from either airborne or ground-deposited radionuclides.

## 1.2 DECOMMISSIONING ALTERNATIVES

One of the major decommissioning objectives for the Jackpile-Paguate mines is reclamation and rehabilitation of the mine waste dumps, open pits, ground surfaces covered with radioactive material, storage areas, and some buildings so as to minimize public exposure to radiation. The five alternative decommissioning proposals to be evaluated are outlined below and are described in more detail in Appendix A:

A. NO ACTION ALTERNATIVE: The mine site would be fenced to control access by humans and livestock. The only use of the site permitted would be additional mining.

B. NO FUTURE USE (Sacrifice Area): All disturbed areas would be covered with about 30 cm (1 ft) of topsoil and revegetated. As above, the mine site would be fenced to control access by humans and livestock, and the only use permitted would be mining.

C1. GRAZING LAND USE (Developed by Anaconda): Protore, all mineralized wastes, and open pits would be covered with 120 cm (4 ft) of overburden. Open pits would be filled with overburden to 90 cm (3 ft) above the groundwater recovery level. (This is the maximum elevation that the groundwater surface would eventually reach under equilibrium conditions). All disturbed and backfilled areas would be covered with 30 cm (1 ft) of topsoil and revegetated. Use of the site would be limited to livestock grazing; human habitation, farming, and construction of commercial and industrial facilities would be excluded.

C2. GRAZING LAND USE (Developed by Task Force): Protore, all mineralized wastes, and open pits would be covered with 120 cm (4 ft) of overburden and then with 30 cm (1 ft) of topsoil. Open pits would be filled to 300 cm (10 ft) above the groundwater recovery level and then covered with 30 cm (1 ft) of topsoil. As under Alternative C1, land use would be limited to livestock grazing.

D. MAXIMUM FUTURE SITE USE: The mine site would be reclaimed as outlined under Alternative C2. However, under this alternative, construction of commercial and industrial facilities, storage, recreation, and further mining, as well as livestock grazing, would be permitted, but habitation and farming would continue to be excluded.

Under each of these alternatives, the entrance and vents to the underground mines would be sealed. The ore remaining on the mine complex would not be transported off the site for milling, but instead would be treated as protore (mine waste) for reclamation purposes.

# 2. PHYSICAL ENVIRONMENT

## 2.1 TOPOGRAPHY

The mine complex is located within the valley formed by the Rio Moquino and Rio Paguate (herein referred to as the Rio Moquino Valley) about 60 km (40 mi) west of Albuquerque. The topography of the region is characterized by broad mesas and plateaus, deep canyons, and broad valleys. Small lava flows and volcanic cones are scattered throughout the area. A topographical map of the site is presented in Figure 2.1(a-c), and typical views of the surrounding terrain are shown in Figures 2.2 and 2.3.

To the northwest of site are the flanks of Mount Taylor, an extinct volcano with an elevation of 3565 m (11,700 ft). Seboyeta Peak, elevation 2075 m (6825 ft), is the highest point immediately north of the mines. To the east of the mines the prominent features are Gavilan Messa [2101 m (6388 ft)], Wiener Mesa [1945 m (6380 ft)], and Snowbird Mesa [1940 m (6365 ft)], which rise above the surrounding broad valleys. To the south of the mines is North Oak Canyon Mesa [1885 m (6185 ft)].

The elevation of the area containing the mine site ranges from 1500 m to 2100 m (5000 to 7000 ft), with most of the mine area at about 1800 m (6000 ft). The lowest area within the region is the Rio Moquino Valley drainage, which extends from the eastern slopes of Mount Taylor through the mine complex to the broad valleys south of the site.

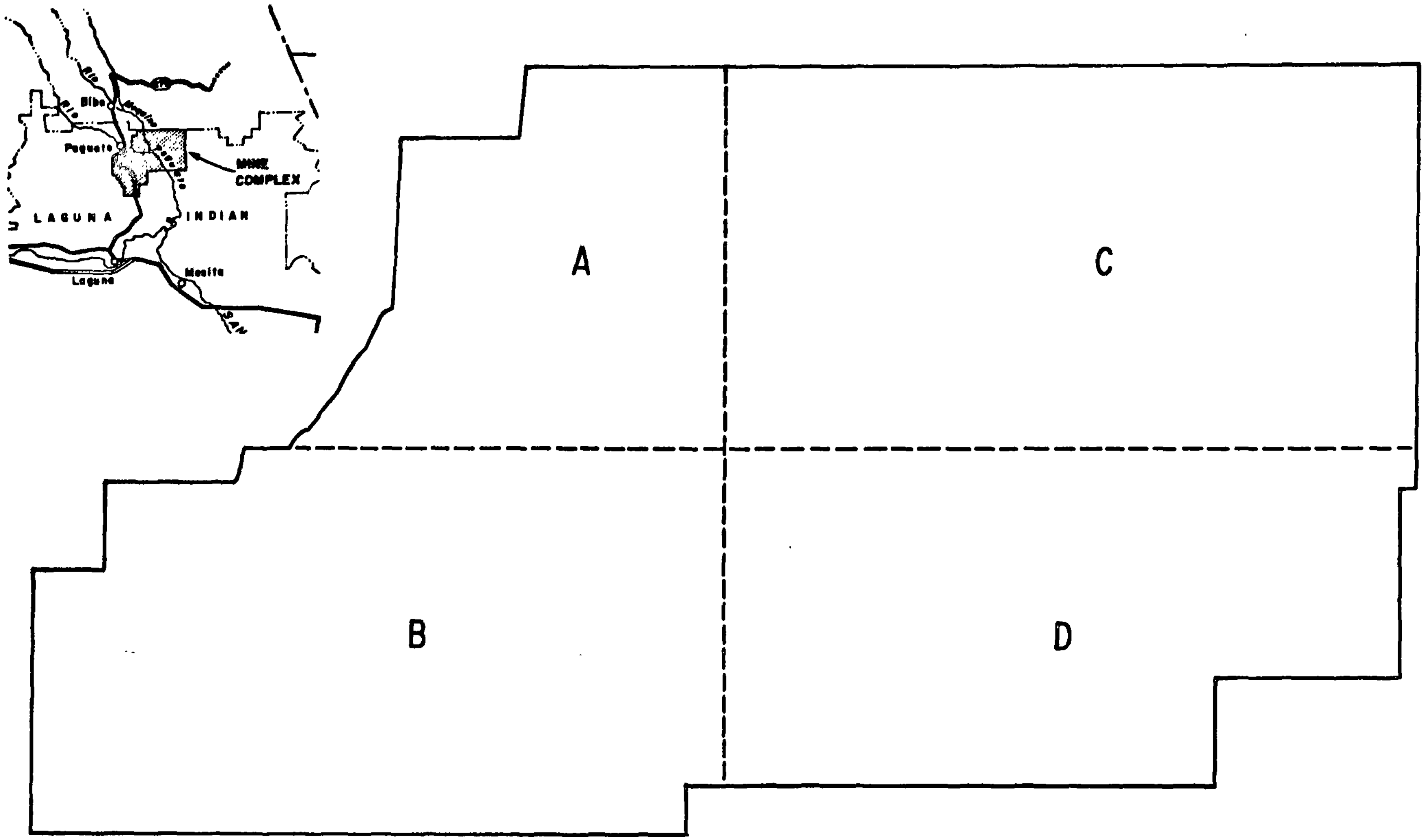
## 2.2 GEOLOGY

The mine area is underlain by consolidated strata of the Mesozoic era and in places is covered by eolian, alluvial, and colluvial deposits. A stratigraphic column of the sedimentary beds in the area is illustrated in Figure 2.4. These strata can be seen in the photographs in Figures 2.5 through 2.7.

The Jackpile sandstone, the host rock of the uranium deposits mined in the Jackpile-Paguate operation, overlies the Brushy Basin mudstone member of the Morrison formation (Freeman and Hilbert 1960). The Jackpile sandstone consists of an area about 55 km (35 mi) long, 25 km (15 mi) wide, and 75 m (220 ft) thick (Kittle 1963). The base of the Jackpile deposit does not exhibit structural conformity,* and transition between the sandstone and the underlying mudstone is not well defined.

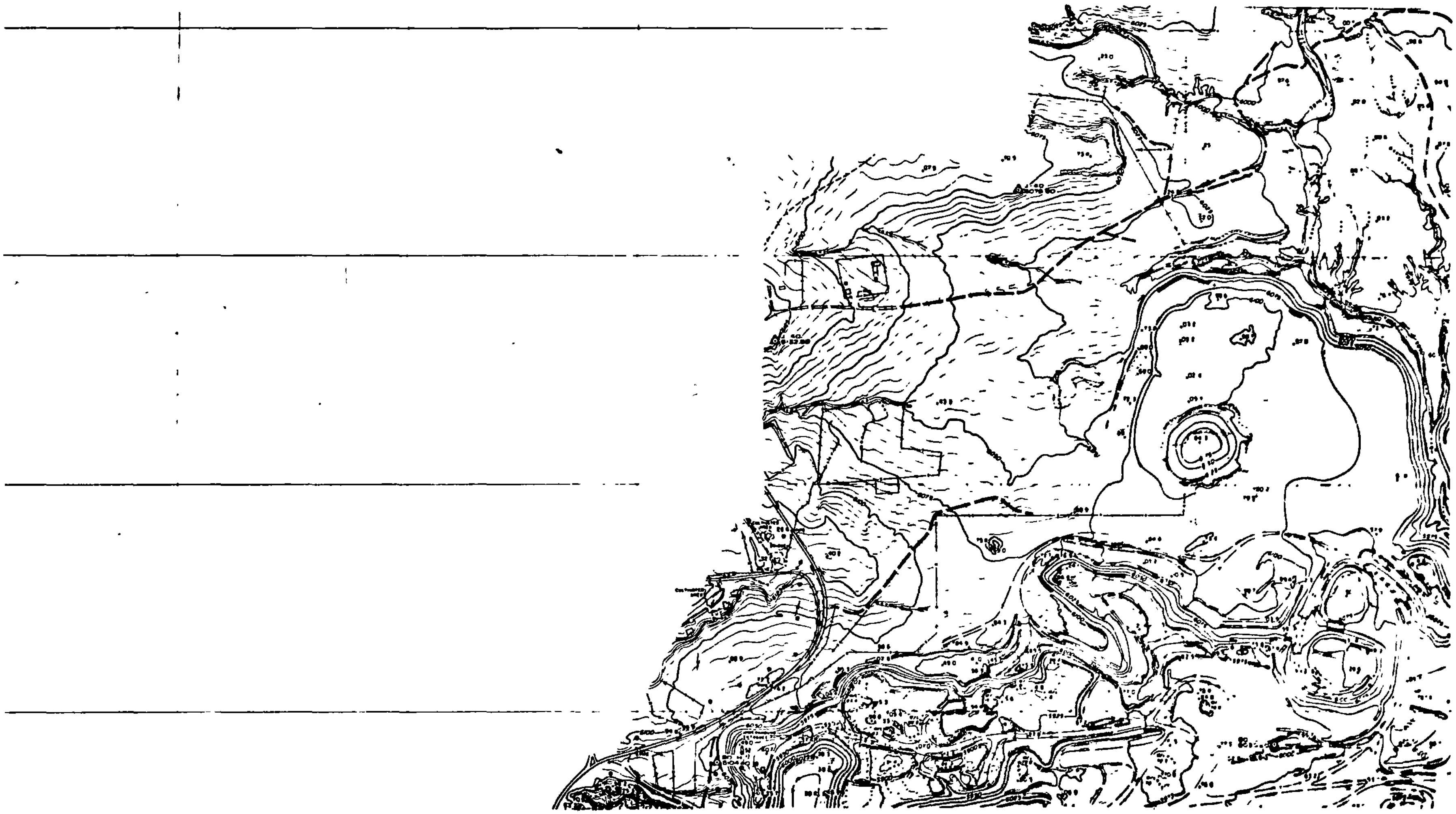
Overlying the Jackpile sandstone bed is the Dakota sandstone. The base of this formation is a hard sandstone and siltstone deposit, and the formation

*Conformity is an uninterrupted sequence of strata that have been deposited in an orderly manner without evidence of folding, tilting, or erosion before the higher strata were deposited.




Key Map

Figure 2.1. Topographic Map of Jackpile-Paguate Mine Complex. (Topography of individual sections is shown on following pages)

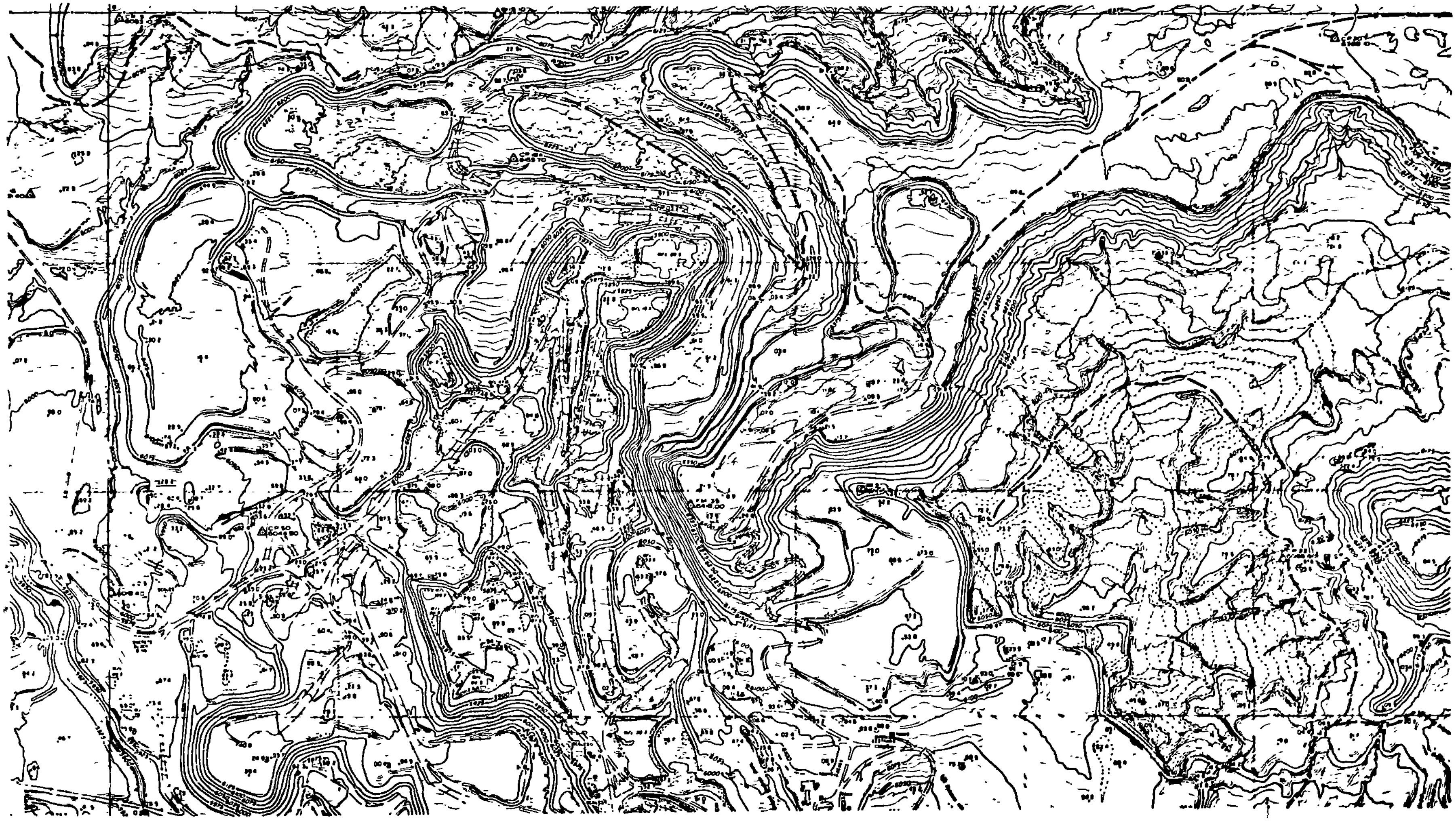


Section A

Figure 2.1. Continued

Section B

Figure 2.1. Continued



Section C

Figure 2.1. Continued

Section D

Figure 2.1. Continued

Figure 2.2. View from Road 279 Looking East over the New Shop Area and Western Gate of the Mine Complex.

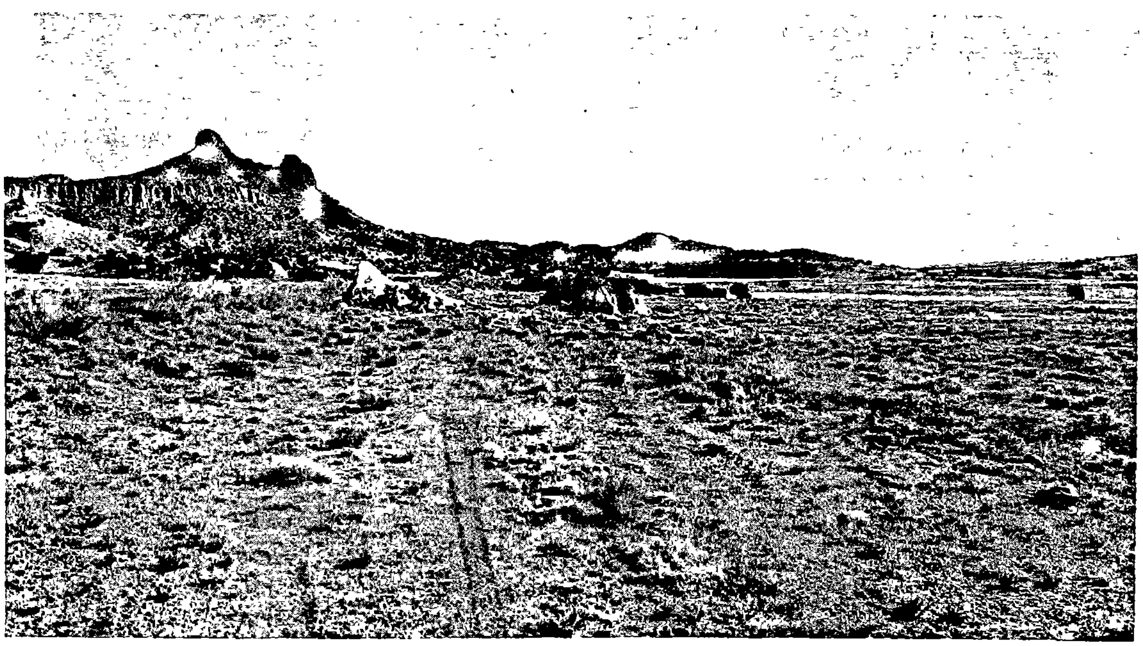


Figure 2.3. View from Road 279 Looking North. (Volcanic cones can be seen in the left of the photograph.)

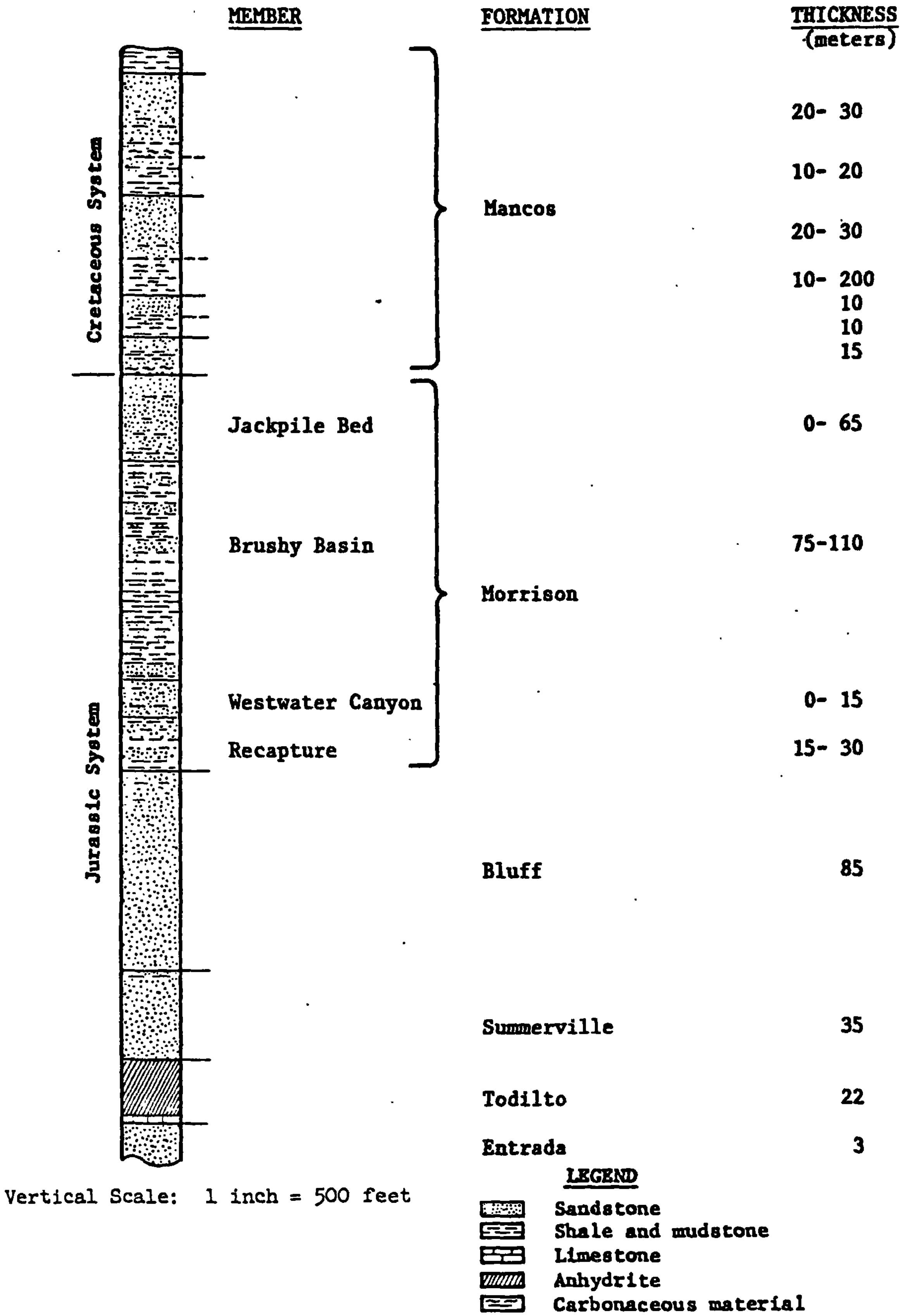



Figure 2.4. Generalized Stratigraphic Column of the Jackpile-Paguate Mine Area. (Vertical scale: 1 cm = 65 m.) [Modified from Kittle 1963.]

Figure 2.5. View East over the North Jackpile Open-Pit Mine. (Dark sandstones of the Dakota Group of the Mancos Formation overlie the gray-white Jackpile sandstone.)

Figure 2.6. A View Southeast over the South Jackpile Mine.

Figure 2.7. A View of Paguate Pit Looking Southwest. (The new shop area is in background in the left-central portion of the photograph.)

gradually changes upward to a soft carbonaceous and shaly siltstone. Above these layers are alternating zones of black Mancos shale and three sandstone units called the Tres Hermanos sandstone. The rocks in the mine area are generally flat-lying, with a regional downward slope (dip) of 2° to 4° to the north-northwest.

An unusual feature of the site geology was the Woodrow breccia pipe, a nearly circular, subsurface geologic structure 7 to 10 m (24 to 34 ft) in diameter (Wylie 1963). Rich uranium ore was mined from this pipe during the period 1954 to 1956.

As ore has been removed, intermixed Dakota and Mancos shales (non-mineralized materials) and Jackpile sandstone with a level of mineralization making it uneconomical to mill have been dumped in some of the mined pits.

## 2.3 HYDROLOGY

### 2.3.1 Surface Water

#### 2.3.1.1 Surface-Water Features

Rio Paguate-Rio Moquino Watersheds

Principal surface drainage features in the vicinity of the mines are the Rio Paguate and the Rio Moquino (Figs. 2.8 through 2.11). The Rio Paguate watershed

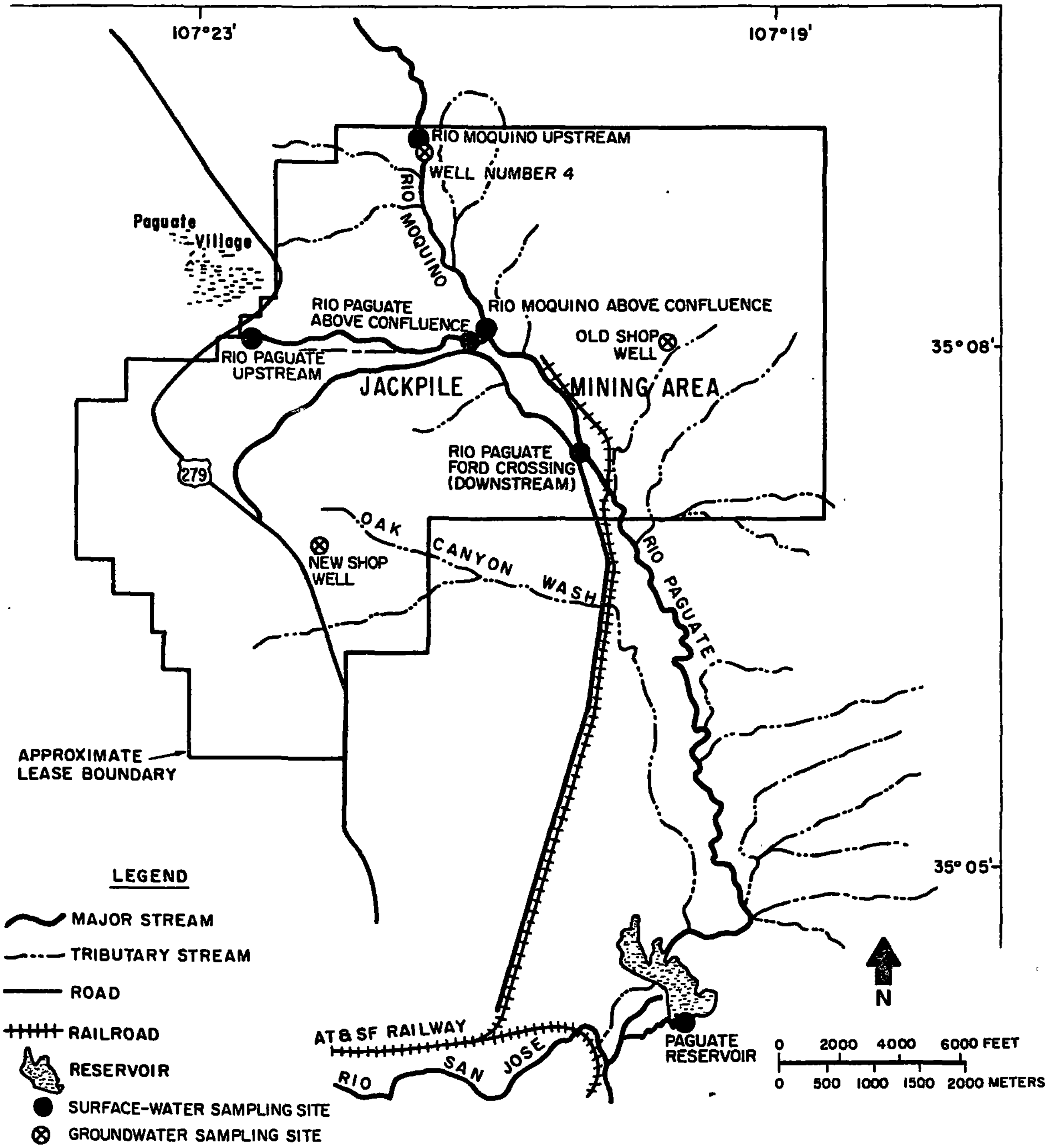



Figure 2.8. Map Showing Locations of Surface Drainage Features and Water-Quality Sampling Sites in the Mine Area. [Modified from Anaconda Minerals Co. base map.]

Figure 2.9. View of Rio Moquino from the Bridge between Seboyeta and Sohio Mill Looking Southward (downstream) toward the Mine Complex.

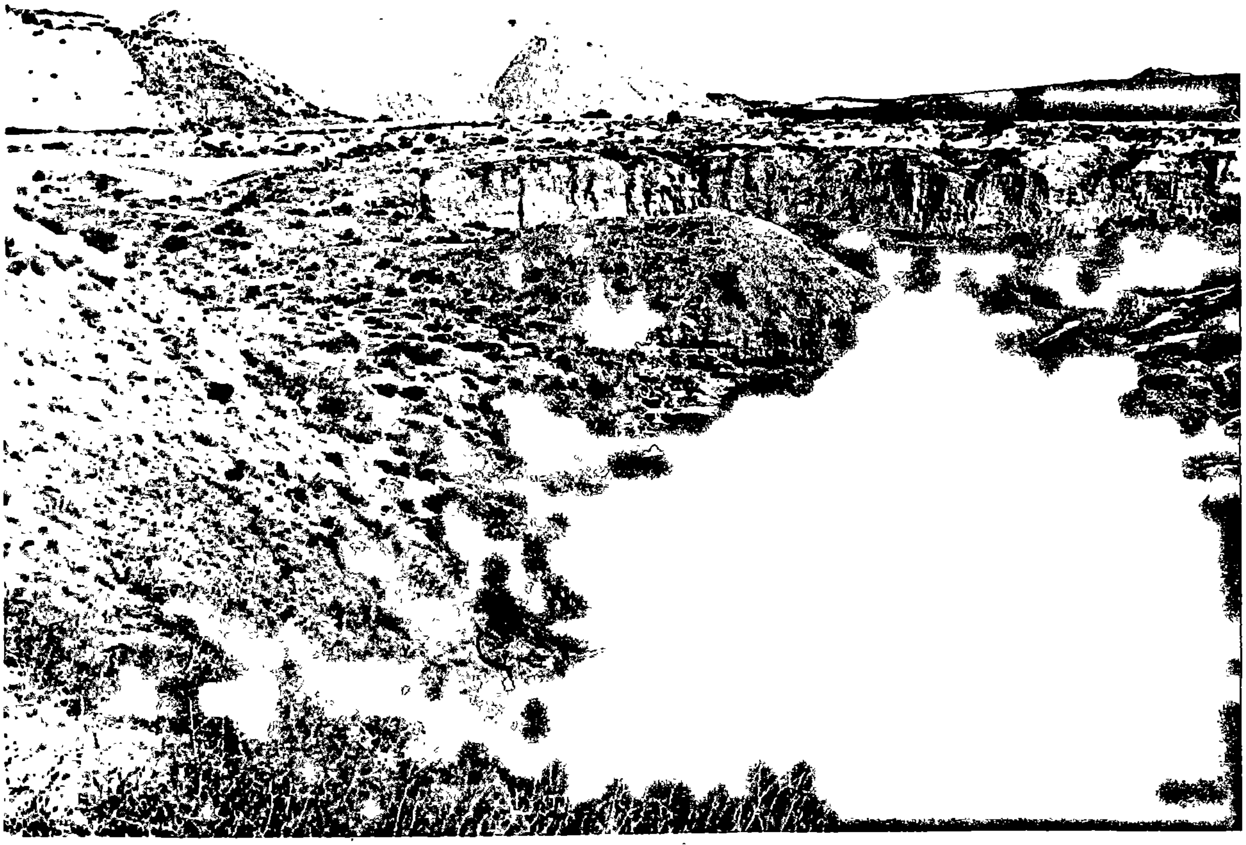


Figure 2.10. Upstream View of Rio Paguate from Road 279 South of the Town of Paguate, Looking East toward the Mine Complex.

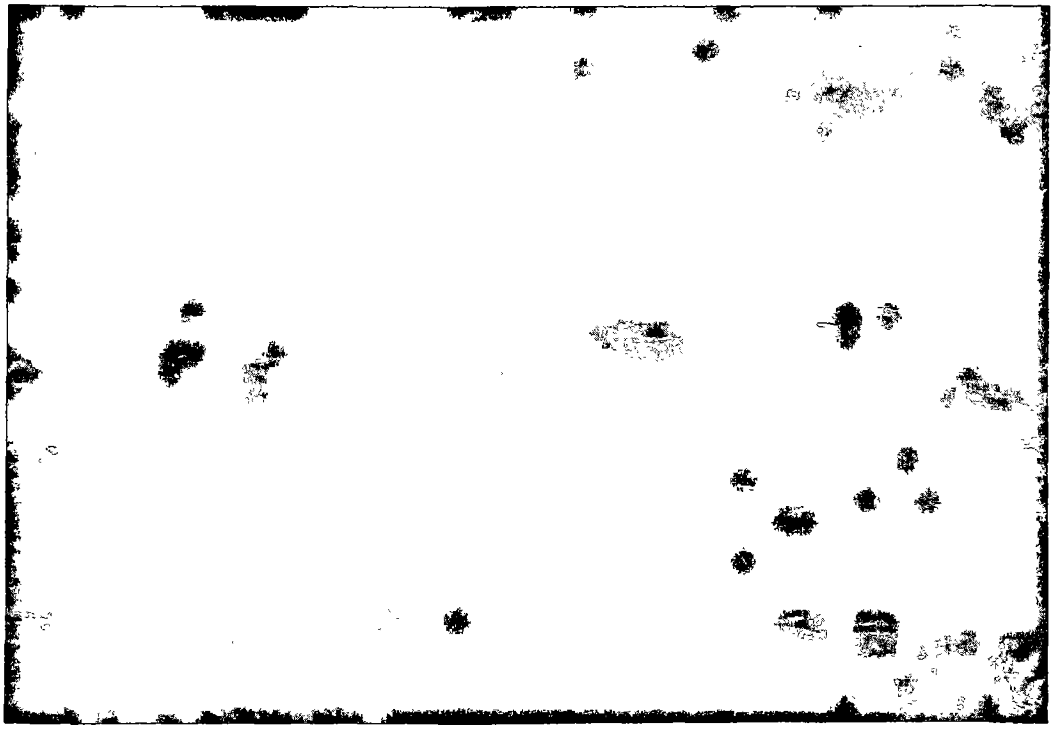


Figure 2.11. View of the Confluence of the Rio Moquino and Rio Paguate (left side of photo) near the Center of the Mine Complex.

originates at the crest of the San Mateo Mountains near Mt. Taylor to the northwest of the mine complex. The river travels generally southeastward from its headwater, flows eastward through the Jackpile-Paguate mining area (where it is joined by the Rio Moquino), then turns southeast until it enters the Paguate Reservoir and discharges into Rio San Jose, about 7.2 km (4.5 mi) south of the mine boundary (Fig. 2.8). The watershed includes about 277 $km^2$ (107 $mi^2$) of drainage area upstream of the mine lease; it is about 27 km (17 mi) long and 11 km (7 mi) wide, with a general southeasterly slope (Zehner 1983; Dames and Moore 1976).

The Rio Paguate was rechanneled during mining operations for a distance of about 600 m (2000 ft) from the point where it enters the western edge of the mine area just south of the town of Paguate. This diversion caused the confluence with Rio Moquino to move about 90 m (300 ft) downstream of its premining location (Herkenhoff and Assoc. 1973).

River flow results primarily from groundwater discharge (Zehner 1983). Although data are sparse, average flows have historically been low. At about 3 km (2 mi) northwest of the town of Paguate the mean daily flow averaged 0.05 $m^3/s$ (1.71 cfs) for the period 1937-1941; for the period 1976-1980, flow averaged 0.03 $m^3/s$ (1.19 cfs) at a point 2.3 km (1.4 mi) south of the confluence of the Rio Paguate and the Rio Moquino (Zehner 1982). Other streamflow surveys conducted in recent years are described in reports by Dames and Moore (1976) and Hydro-Search (1981).

About 60% of the total annual precipitation in the Rio Paguate watershed occurs from May through September (Dames & Moore 1976). The annual precipitation averages about 370 mm (14.5 in), increasing northward and varying from a low of about 250 mm (10 in) at the mine lease area to a high of about 750 mm (30 in) near the summit of Mt. Taylor. Average annual runoff at the mouth of the watershed is estimated to be about $12.1 \times 10^6$ $m^3$ (9800 ac-ft) (Dames & Moore 1976). This runoff represents about 11.5% of the mean annual precipitation of about 370 mm (14.5 in).

Rio Moquino, the major tributary to the Rio Paguate, has a drainage area of about 190 $km^2$ (73 $mi^2$) above its confluence with Rio Paguate. The Rio Moquino enters the mine lease area from the north and flows south until it meets the Rio Paguate at the center of the mine lease. Rio Moquino may become intermittent in the upper parts of the mine area in July and August. During these low-flow periods, seepage can be observed from the stream banks as a result of groundwater discharge near the confluence of Rio Paguate and Rio Moquino (Anaconda 1980). Some channel modification has been carried out on the Rio Moquino between the "T" and "U" dumps (as shown in Fig. 2.12) within the mine lease area by placing excavated material along both sides of the original channel (Anaconda 1980). This results in a relatively straight course for the rechanneled reach.

Blocked Arroyos

Three arroyos (washes) on the mine site have been blocked as a consequence of mining operations. Characteristics of the three blockage areas are given in Table 2.1. (The locations of two blockages are shown in Fig. 2.13, and a photograph of one is presented in Fig. 2.14.) These arroyos are normally dry except for short periods (days) after rainstorms. The water from these blocked watersheds occasionally may be ponded at the point of blockage.

#### 2.3.1.2 Surface Water Quality

Water samples are collected monthly by Anaconda at six surface-water-monitoring stations as shown in Figure 2.8. One sampling location is at the Paguate Reservoir south of the mine lease.

Monitoring data given in Table C.1 of Appendix C indicate that an increase in concentrations of dissolved chemical species and radioactive constituents in surface waters occurs through the mine area. However, concentrations of minor constituents do not increase significantly through the mine area. Rio Moquino usually contains high concentrations of dissolved constituents in comparison with the upper Rio Paguate. The total dissolved solids (TDS) level of Rio Paguate below the confluence with the Rio Moquino is usually higher than that of Rio Paguate above the confluence and usually lower than that of the Rio

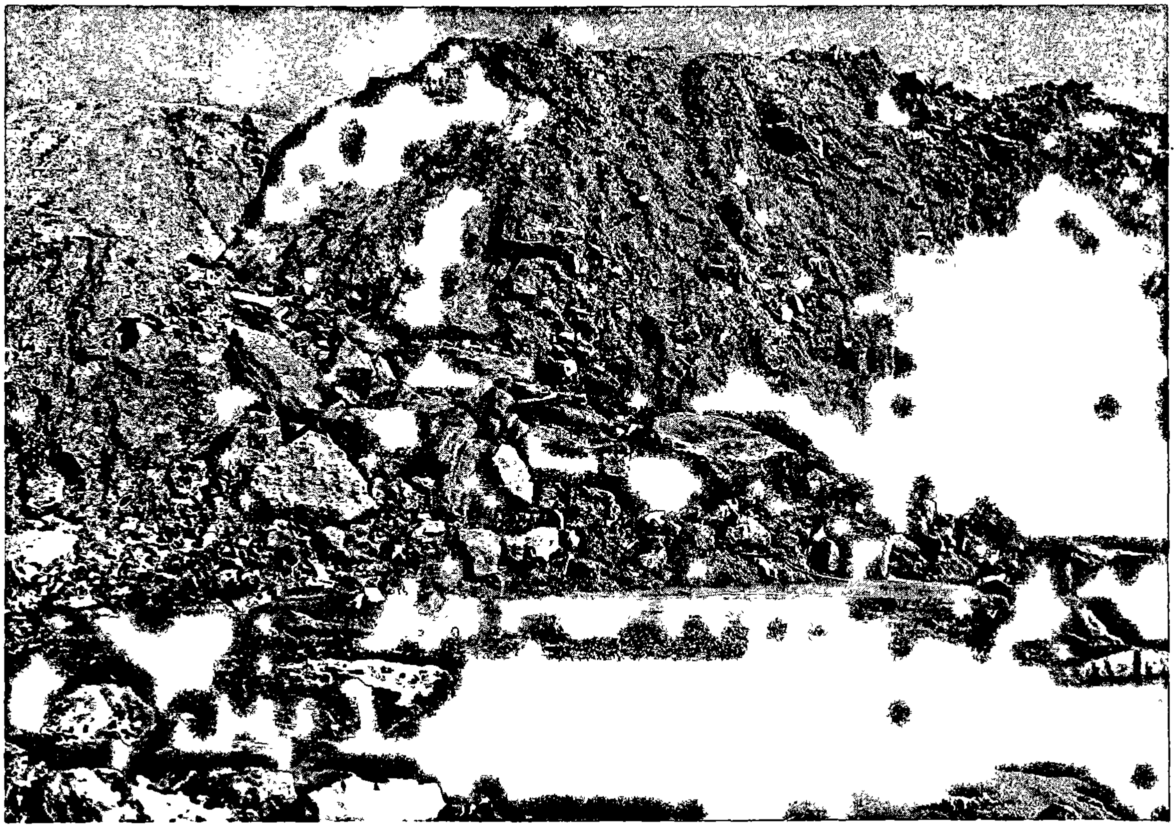


Figure 2.12. Photograph of the Rio Moquino within the Mine Complex. (The streambed was altered by mining of the ore below the stream.)

Table 2.1. Characteristics of Blocked Watersheds†[1,2]

| Characteristic | Watershed #1 | Watershed #2 | Watershed #3 |
|---|---|---|---|
| Drainage area ($km^2$) | 4.40 | 2.31 | 1.79 |
| Average slope of watershed (% grade) | 3.64 | 6.81 | 4.45 |
| Curve number | 86.00 | 86.00 | 86.00 |
| Watershed lag (hours) | 0.95 | 0.45 | 0.54 |
| Time of concentration (hours) | 1.59 | 0.75 | 0.90 |
| 100-year 24-hour rainfall (mm)†[3] | 89 | 89 | 89 |
| Runoff depth (cm) | 5.33 | 5.33 | 5.33 |
| Runoff volume ($m^3$) | $2.34 \times 10^5$ | $1.23 \times 10^5$ | $0.95 \times 10^5$ |
| Peak discharge (cms) | 22 | 19.5 | 13.3 |

†[1] Calculations based on methods recommended by the U.S. Soil Conservation Service (1957).

†[2] Locations shown on Plate 4.2-1 of Dames & Moore 1976.

†[3] From U.S. Weather Bureau Technical Paper No. 40.

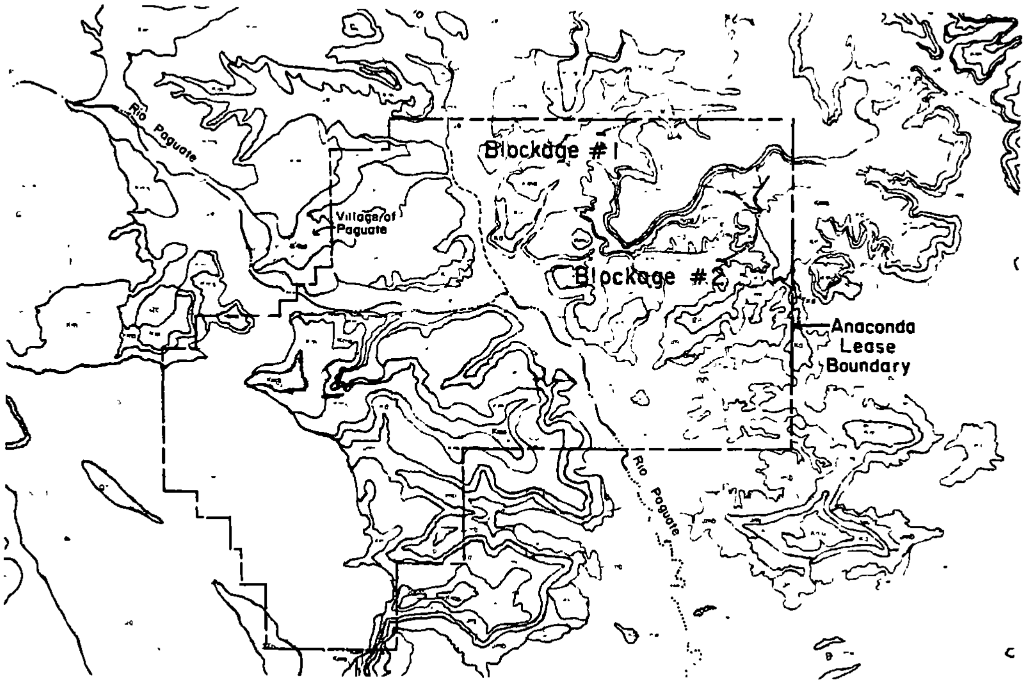



Figure 2.13. Map Showing Locations of Two Blockage Areas on Mine Site. (Modified from Hydro-Search 1981b.)

Figure 2.14. Photograph of Blocked Arroyo. (View is eastward over waste pile F. Ponded water is from melted snow and rainfall.)

Moquino above the confluence. The mean concentrations of uranium and Ra-226 in surface waters are less than the water quality standards of 5 mg/L and 30 pCi/L, respectively, set by the New Mexico Environmental Improvement Agency. However, sites on the Rio Paguate immediately above and below the confluence with Rio Moquino occasionally had Ra-226 values exceeding the EPA limits of 5 pCi/L. More detailed data on surface water quality are presented in other reports (Hydro-Search 1979, 1981b; Dames & Moore 1976).

### 2.3.2 Groundwater

#### 2.3.2.1 General Characteristics

In the mine area, groundwater is present in the surficial alluvial stream deposits and in the deeper water-bearing bedrock formations. Groundwater characteristics for various geologic strata are summarized in Table 2.2.

In March 1979 and during the period June 10-12, 1981, the potentiometric surface for the Jackpile sandstone in the Jackpile pit area was measured at between 1789 and 1820 m (5868 and 5960 ft) MSL. In the Paguate pit area, the groundwater was between 1795 and 1830 m (5890 and 6010 ft) MSL (Fig. 2.15). The potentiometric surface for water in the Jackpile sandstone slopes from an elevation of about 1830 m (6010 ft) MSL at the South Paguate pit in a northeastward direction toward the North Paguate pit, then eastward to the confluence of Rio Paguate and Rio Moquino. It also slopes from an elevation of about 1820 m (5960 ft) MSL at the Jackpile pit in a westward direction, then southward to the confluence of the streams. In general, the water table is at depths of less than 15 m (50 ft) below the stream valleys and more than 90 m (300 ft) beneath the high mesas (Hydro-Search 1981a).

The Dakota sandstone overlying the Jackpile sandstone does not contain significant amounts of groundwater in the mine area (Dames & Moore 1976). The Dakota unit contains variably cemented sandstone and dark shale, particularly in the lower portion. The shales act as confining layers to the Jackpile sandstone in the northern and western parts of the mine area. Underlying the Jackpile sandstone is the Brushy Basin member, with a thickness of about 6 to 80 m (20 to 275 ft) of mudstones. It forms a relatively continuous impervious layer because of its fine-grained, well-cemented matrix. Therefore, the Jackpile sandstone is bounded above and below by layers with significantly lower hydrologic conductivity.

In general, groundwater under the area flows from recharge areas to the southwest and northeast of the mine site mostly toward the mine pits and underground mines and then discharges to both Rio Paguate and Rio Moquino in the vicinity of the confluence of the streams.

Recharge to surficial alluvial materials and Jackpile sandstone in the mining site probably occurs from direct infiltration of precipitation and streamflow; recharge to consolidated strata results from infiltration along their outcrop areas and from vertical leakage through overlying strata. Discharge from the Jackpile sandstone occurs as evapotranspiration, discharge to streams, and evaporation of ponded groundwater in the open mine pits. Evapotranspiration occurs in the summer months in areas where the Jackpile sandstone is close enough to the surface that roots of phreatophytic vegetation can reach the groundwater. The Jackpile sandstone is hydraulically connected with Rio Paguate and Rio Moquino, and groundwater can discharge into these two streams

Table 2.2. Groundwater Characteristics of Various Geological Strata†[1]

| Formation/ Member | Yield and Water-Bearing Properties†[2,3] |
|---|---|
| Eolian and alluvial deposits | Yields of 15 to 90 gpm reported in Paguate area near perennial streams. Water quality good. |
| Colluvial deposits | Mostly above water table. |
| Dikes and sills | Unknown; presumed poor. |
| Tres Hermanos | |
| Mancos shale | Yields from Tres Hermanos range from 5 to 20 gpm. Water quality probably fair to good in vicinity. |
| Dakota sandstone | Yield of 5 gpm reported. |
| Morrison | |
| Jackpile sandstone | Yields of 8 to 34 gpm reported. Water quality fair to poor. |
| Brushy Basin member | Well No. 4 reportedly yielded 100 gpm from sand units; 25 gpm from Paguate Shop well. Quality fair to poor. |
| Westwater Canyon member | Yields of 5 gpm reported in Well No. 5; quality poor. |
| Recapture member | Not known to yield water to wells in area. |
| Bluff sandstone | Yields to 15 gpm reported. Quality poor. |
| Summerville formation | Not known to yield water to wells in area. |
| Todilto formation | Not known to yield water to wells in area. |
| Entrada sandstone | Yield of 5 gpm reported in well south of area; 16 gpm reported in well producing from Entrada sandstone and underlying Chinle Formation. Quality believed poor. |

†[1] A generalized stratigraphic column of the area is presented in Figure 2.4.

†[2] Conversion: 1 gpm (gallon per minute) = 0.06309 L/s (liter per second).

†[3] Water Quality - "Good" for TDS < 500 ppm and $SO_4^{=}$ < 250 ppm;
"Fair" for 500 ppm < TDS < 1000 ppm and $SO_4^{=}$ < 300 ppm;
"Poor" for 1000 ppm < TDS and $SO_4^{=}$ > 300 ppm.

Modified from Dames & Moore 1976.

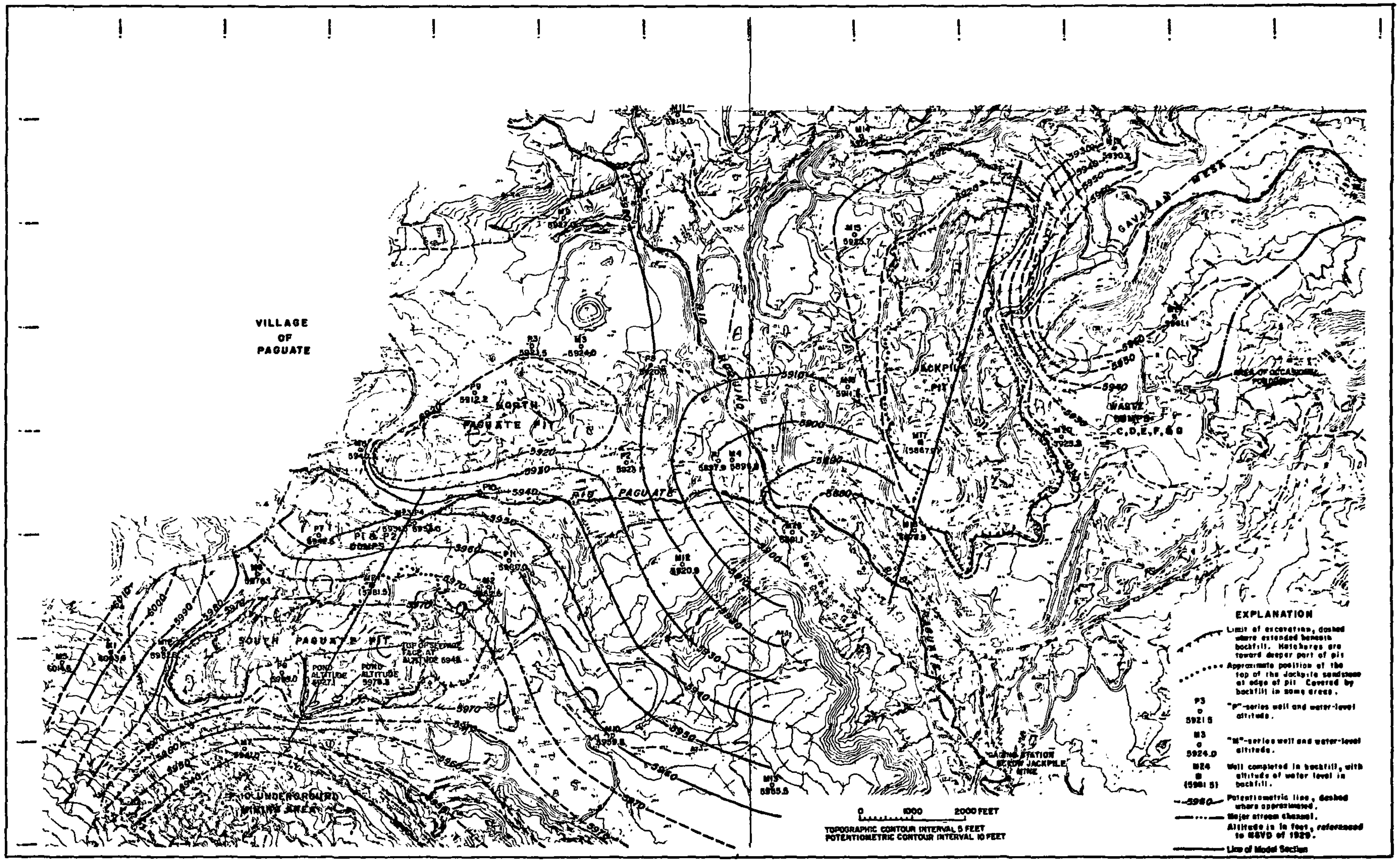



Figure 2.15. Water Table Configuration in the Jackpile-Paguate Mine Area. [Modified from Zehner 1982.]

from bedrock and alluvial materials. The surficial alluvial deposits and the water table slope toward the Rio Paguate and Rio Moquino.

The Rio Paguate loses water along the reach from the western edge of the mine area to a point about 300 m (1000 ft) above the confluence with the Rio Moquino. This indicates that the Rio Paguate recharges the backfill and then flows through the underlying Jackpile sandstone and the alluvium along this reach (Hydro-Search 1979). The total net gain in groundwater flow through the Jackpile sandstone near the confluence of the Rio Paguate and the Rio Moquino was estimated at about 1.4 L/s (22 gpm) on December 3-4, 1980 (Hydro-Search 1981a). Information about groundwater yield, hydraulic characteristics, and results of recent aquifer tests are reported in several publications (Hydro-Search 1981a; Zehner 1982; Lyford 1977).

### 2.3.2.3 Quality

Three monitoring wells, Jackpile Well #4, Jackpile New Shop, and Jackpile Old Shop (see Fig. 2.8), have been sampled by Anaconda for about 20 years. The mean concentrations of chemical and radiological constituents of water samples from these wells are summarized in Appendix C. Consolidated rock in the mine area yields water of generally poor quality. Well #4 is located hydraulically upgradient from all the mine workings and presumably monitors the ambient groundwater quality of sandstone units in the Brushy Basin member. Normally, the groundwater from well #4 is of higher quality than water from the two other wells. Samples from the Old Shop well contained a mean concentration of 0.18 ppm of selenium, which exceeds the 0.05 ppm standard set by the State of New Mexico.

Eleven "P"-series wells were completed in 1977 by Hydro-Search Inc. to investigate effects of two holding ponds on the quality of the groundwater system in the mine area (Hydro-Search 1979). Thirty "M"-series wells were installed about 1980 in the lease area for a general hydrogeologic study (Hydro-Search 1981a). Most of these wells are open to the alluvium and the Jackpile sandstone. The concentrations of radiological constituents (except Ra-226) in water collected from Jackpile sandstone through 11 "P"-series wells, 16 "M"-series wells, and four additional offsite wells are generally low. The Ra-226 concentrations in four of the wells are close to the maximum permissible concentrations (MPC) of 30 pCi/L as proposed by the State of New Mexico and greater than the MPC of 5 pCi/L as proposed by the U.S. EPA for a public water supply (Hydro-Search 1981b).

## 2.4 METEOROLOGY AND CLIMATOLOGY

New Mexico has a generally mild, arid to semiarid, continental climate characterized by abundant sunshine, low relative humidities, low precipitation, and relatively large annual and diurnal temperature variations (Houghton 1972; NOAA 1959-1980). As inferred from data on temperature, precipitation, and evaporation for the Laguna area (Tables 2.3 and 2.4), this same pattern occurs in the region of the mines.

Weather data collected at Laguna since 1927 were used to characterize the climate in the mine area. Data from Marquez, 24 km (15 mi) north of the mines, Las Lunas, about 55 km (35 mi) southwest, San Mateo, 40 km (25 mi) northwest, and Grants, 40 km (25 mi) west-northwest, were used for those few periods when data for Laguna were missing.

Table 2.3. Temperature and Precipitation Data for Laguna, New Mexico, Area (1951-1980)

| Month | Monthly Temperatures (C°)†[1] Minimum | Mean | Maximum | Mean Precipitation†[2] (mm) |
|---|---|---|---|---|
| January | -3.4 | 0.8 | 4.8 | 8.4 |
| February | -1.9 | 3.0 | 7.3 | 10.7 |
| March | 2.7 | 6.2 | 10.3 | 9.9 |
| April | 7.8 | 10.7 | 15.1 | 7.4 |
| May | 13.4 | 15.7 | 18.0 | 14.2 |
| June | 18.9 | 21.3 | 23.2 | 10.9 |
| July | 21.9 | 23.7 | 25.5 | 41.1 |
| August | 20.8 | 22.3 | 23.7 | 48.0 |
| September | 16.6 | 18.5 | 21.0 | 27.4 |
| October | 10.1 | 12.5 | 14.9 | 28.7 |
| November | 2.8 | 5.6 | 7.7 | 7.6 |
| December | -3.6 | 1.2 | 4.9 | 12.2 |
| Annual | | 11.8 | | 226.3 |

†[1] Because of missing data from Laguna, one month of data from San Mateo (40 km NW) and eight months of data from Grants (40 km WNW) were substituted to make the period of record complete.

†[2] Eight months of data from Marquez (24 km N) were substituted to make the period of record complete.

Table 2.4. Evaporation (mm) at Laguna for the Months of June through October, 1976-1980

| Year | June | July | August | September | October |
|---|---|---|---|---|---|
| 1976 | 332.5 | 292.6 | 243.6 | 149.4 | 136.1 |
| 1977 | 285.0 | 261.9 | 242.8 | 172.0 | 141.2 |
| 1978 | 324.9 | 304.3 | 248.2 | 183.9 | 150.4 |
| 1979 | 260.1 | 272.5 | 227.8 | 188.5 | 170.7 |
| 1980 | 343.9 | 309.4 | 251.2 | 205.5 | 131.3 |
| Average | 309.4 | 288.0 | 242.8 | 179.8 | 146.1 |

Modified from NOAA 1976-1980.

As indicated in Table 2.3, monthly temperatures over the period 1951 through 1980 ranged from an average minimum of -3.6°C (25.6°F) in December to an average maximum of 25.5°C (77.9°F) in July.

Precipitation in the area is light, and about 65% of the rain that falls occurs July through October, mostly during brief, but frequently intense, thunderstorms. Annually about 45 thunderstorm days occur in the area (Houghton 1972). Snowfall is light and results primarily from frontal activity associated with Pacific storms moving through the area. Accumulation of snow is uncommon because the mean maximum daily temperature in January is about 8°C (46°F).

For the period 1927 through 1980, the annual average precipitation was 235 mm (9.25 in). Specifically for the mining period (1951 through 1980), the annual average precipitation was 226 mm (8.91 in). Examination of data on the cumulative annual departure of precipitation from the average, as shown in Figure 2.16, indicates that a dry period occurred in the 1950s and 1960s.

The combination of low total precipitation and abundant sunshine results in an annual deficit of moisture. For 1976 through 1980, average evaporation for Laguna during the period June through October was about 1150 mm (45 in) (see Table 2.4). The estimated annual evaporation rate is about 1800 mm (70 in) (Chow 1975). A comparison between the potential monthly evaporation and precipitation rates is shown in Figure 2.17. The average evaporation rate exceeds the average precipitation rate each month.

Tornadoes are rare in this area. The size, wind velocity, path length, and damage of those tornadoes that do occur are considerably less than those that occur in the Great Plains or Midwest. Between 1914 and 1968, only four tornadoes were reported in Cibola County (NWSFO 1975). As one would expect, weather activity associated with hurricanes also is rare in the area, but the passage of a downgraded hurricane or tropical storm that has moved inland from either the Pacific Ocean or Gulf of Mexico can cause increased rainfall at the mine site.

Surface winds at the mine area are monitored by the Anaconda Company with instruments located on a tower 18 m (60 ft) above ground, mounted on the roof of the mine maintenance shop. However, because of the irregular terrain in the area, the wind data collected at this tower are believed to be representative only of the wind field in the immediate area of the sensors. The orientation of the Rio Moquino Valley is NNW-SSE, but the tower is at the head of a small canyon bordered by two small ridges that are oriented E-W (see Figs. 2.18 and 2.19).

The daily wind distribution as recorded at the tower is shown graphically in Figure 2.20. Nocturnal drainage winds (occurring from midnight to 6 a.m.) are light, westerly breezes [<10 km/h (<5 mph)] that result from the movement of cooler, more dense air flowing down from the higher terrain to the west. During the morning (6 a.m. to noon), upslope flow (easterly winds) occurs. During the afternoon (noon to 6 p.m.), winds become more variable as a result of increased solar insulation and subsequent thermal turbulence. In the evening (6 p.m. to midnight) the upslope (easterly) flow virtually disappears, and the dominant wind direction returns to the west.

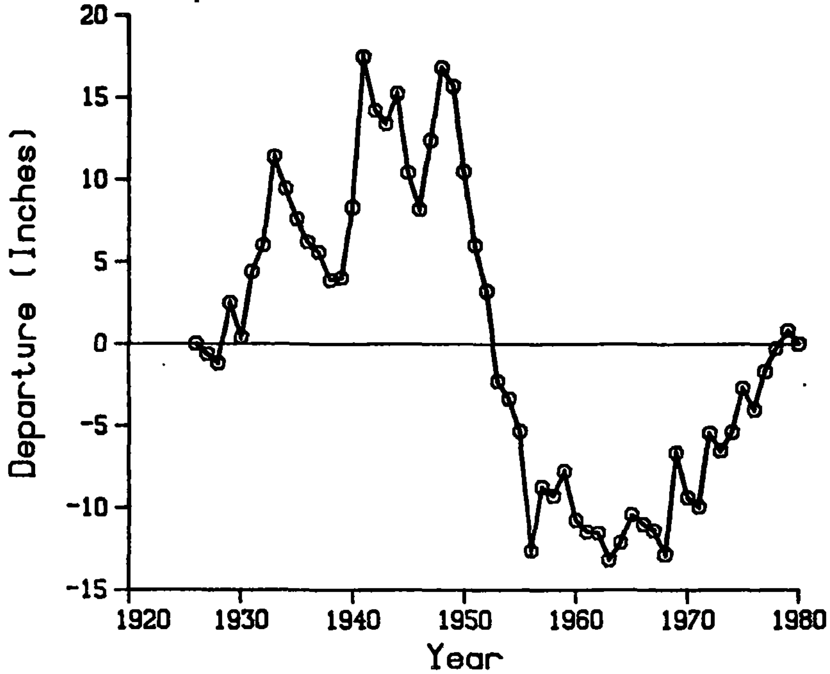



Figure 2.16. Cumulative Departure from Normal Precipitation at Laguna for the Period 1926-1980. (Average annual precipitation is 9.25 inches.)

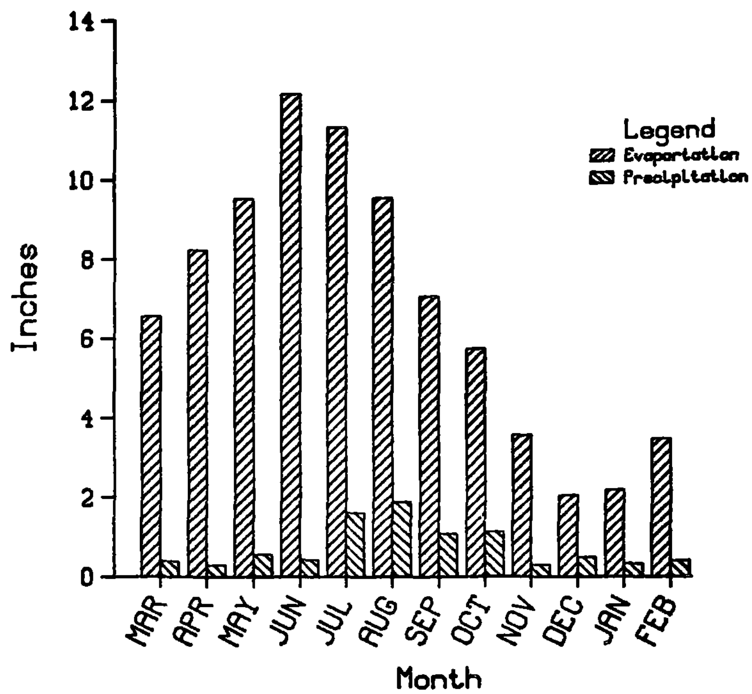



Figure 2.17. Potential Evaporation Rates and Precipitation Amounts for Laguna.

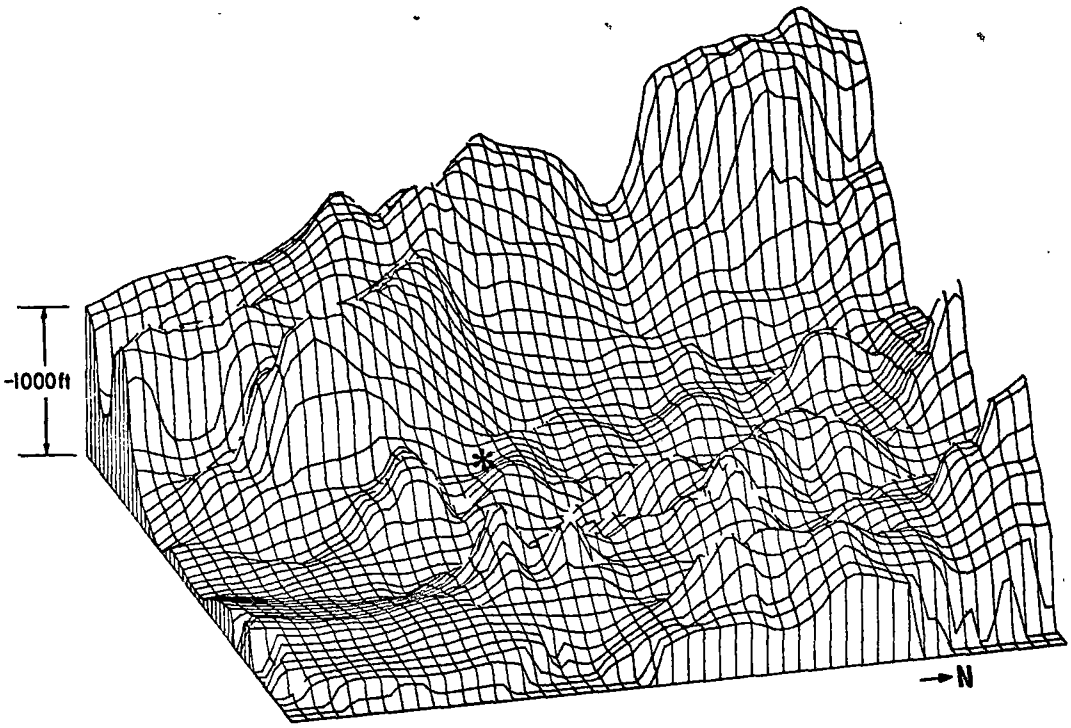



Figure 2.18. Computer-Generated 3-Dimensional Perspective of the Region around the Jackpile-Paguate Mine Complex--20° above the Surface. (Asterisk ('*') shows location of the meteorological sensors.)

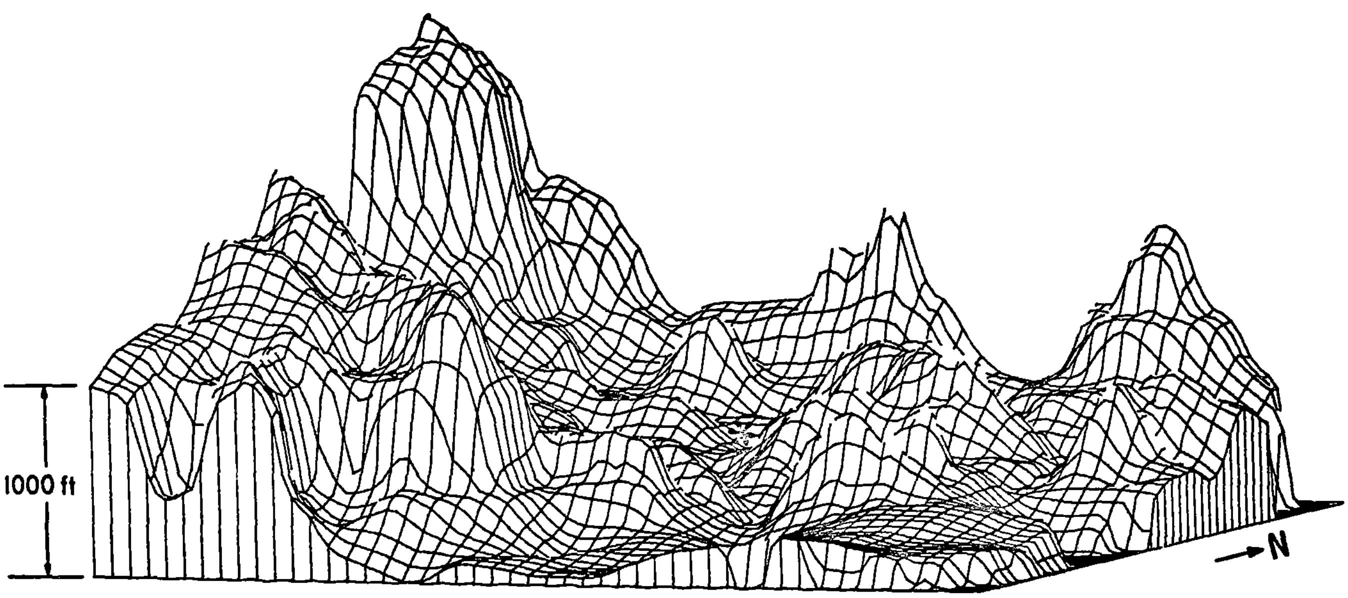



Figure 2.19. Computer-Generated 3-Dimensional Perspective of the Region around the Jackpile-Paguate Mine Complex--5° above the Surface. (Asterisk ('*') shows location of central mine area.)

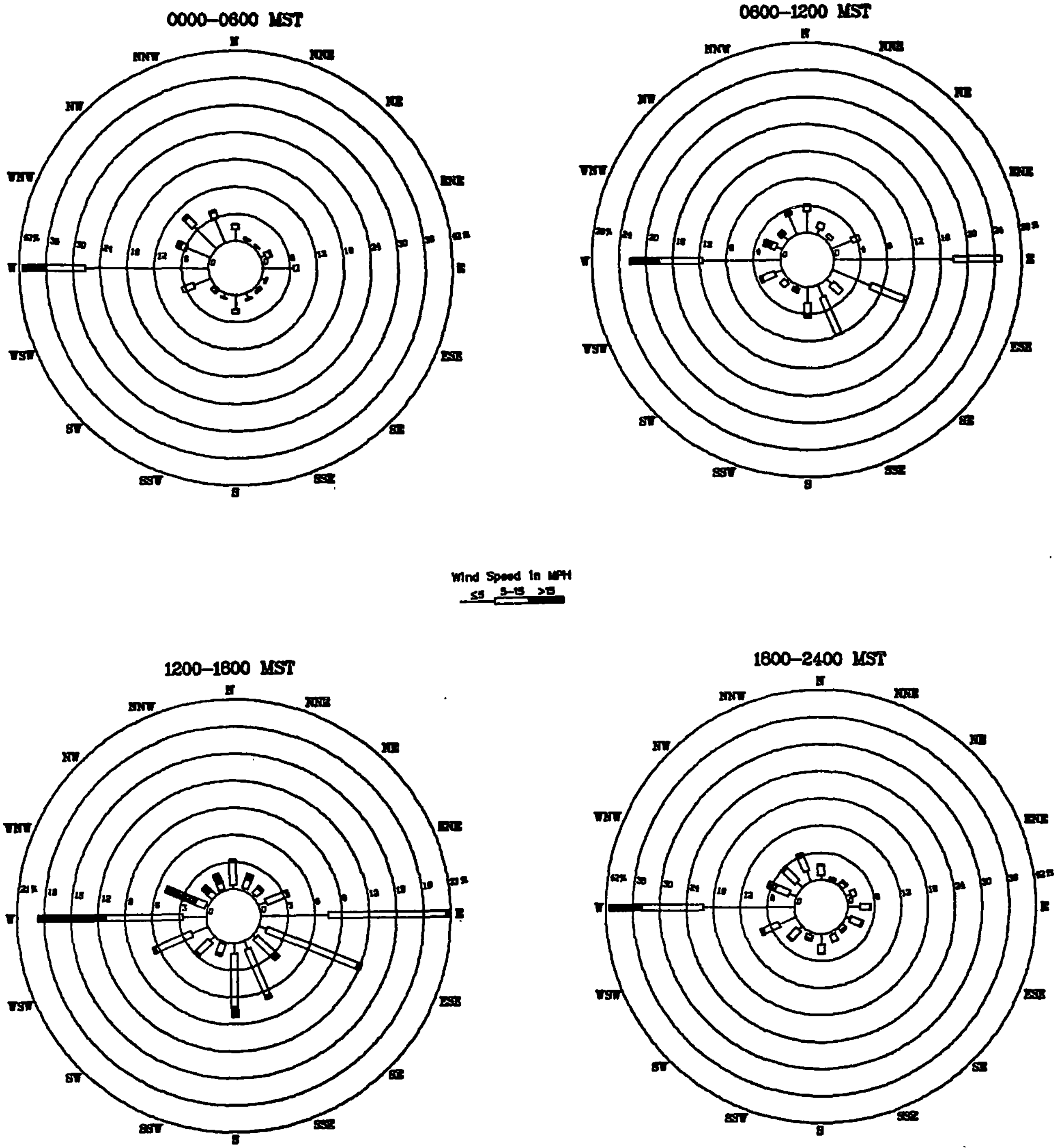



Figure 2.20. Distribution of Surface Winds as Recorded at the Jackpile-Paguate Meteorological Tower. (Period of record was May 1974 through January 1975.)

The data collected at the mine maintenance shop have been modified to represent the orientation of the Rio Moquino Valley by rotating compass directions 67.5°. The resulting wind rose, which is believed to be more representative of the wind pattern of the valley as a whole, is shown in Figure 2.21. Calculations of the dispersion of radioactive nuclides released from the Jackpile-Paguate mines as reported in this document were based on this modified wind field.

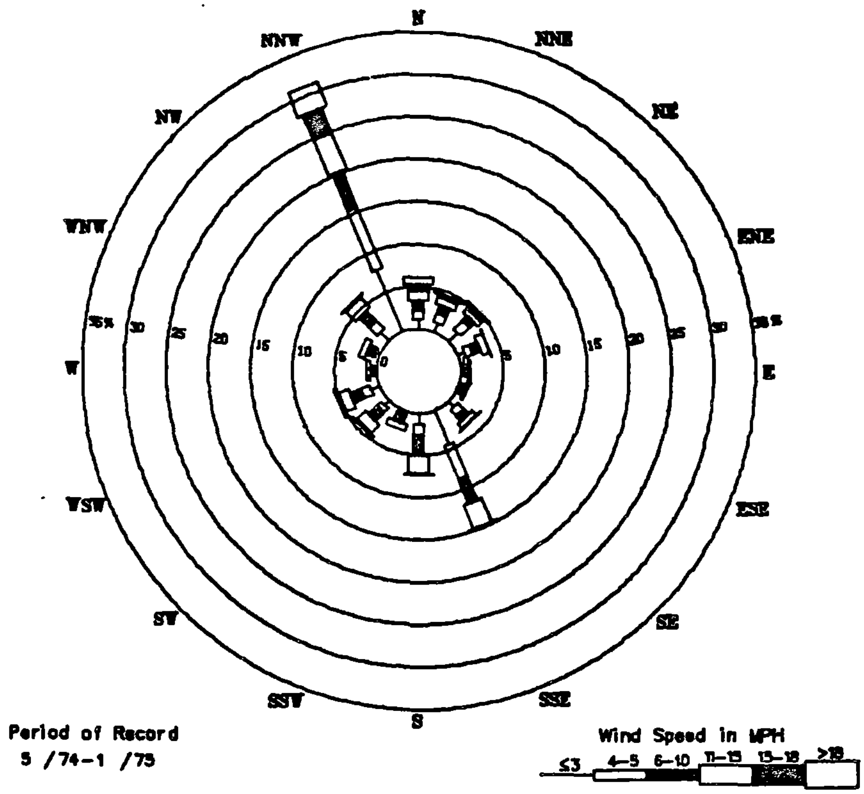



Figure 2.21. Modified Wind Rose for the Rio Moquino Valley.

## 2.5 NATURAL AND BACKGROUND RADIATION

The radiation environment in the vicinity of the Jackpile-Paguate mines consists of three major components: (1) natural radiation, (2) radiation resulting from human activities other than Jackpile-Paguate mining operations, and (3) radiation attributable to the mining activities. The background radiation environment of the mines consists of the first two components. The level of background radiation is the baseline for determining the effectiveness of control technologies incorporated in each of the decommissioning alternatives for the mines.

The sources, types, and variations in background radiation and subsequent human exposure in the United States have been reviewed by Oakley (1972), Klemment (1972), the U.S. Environmental Protection Agency (USEPA 1972, 1976, 1977), National Council on Radiation Protection and Measurements (NCRP 1975), Gesell (1974), and Gesell and Lowder (1980). The levels of background radiation have been estimated by Oakley (1972), Klemment (1972), and NCRP (1975) for several locations throughout the country.

### 2.5.1 Natural Radiation Environment

Natural radiation consists of cosmic radiation, terrestrial radiation, and human body burden. Cosmic radiation originates in the cosmos and enters the earth's atmosphere; terrestrial radiation originates from the naturally occurring radionuclides in the soil; and human body burden originates from ingestion of naturally occurring radionuclides in food and water and from inhalation of naturally occurring airborne radionuclides. The level of natural radiation in any particular area depends on such factors as altitude, local geology, meteorological conditions, and vegetation type. Exposure to the natural radiation may also depend on such factors as personal lifestyle, diet, and type of residence.

#### 2.5.1.1 Cosmic Radiation

Primary cosmic radiation is radiation that enters the earth's atmosphere from extraterrestrial sources. The interaction of this radiation with the atmosphere results in production of secondary cosmic radiation. The intensity of cosmic radiation at a location on the earth's surface depends on the altitude of that site. The average altitude at the Jackpile-Paguate mines is about 1800 m (6000 ft). At this altitude, the total cosmic radiation dose-rate equivalent is about 70 mrem/yr at a tissue depth of 5 cm (NCRP 1975).

#### 2.5.1.2 Terrestrial Radiation

Concentrations of naturally occurring radionuclides in the top 25-cm (10-in) surface layer of the earth determine the intensity of terrestrial gamma radiation. The intensity of beta radiation is strongly reduced by absorption in the soil. Exposure to these radiations is also influenced by lifestyle and type of housing. The terrestrial whole-body dose-rate equivalent for the Colorado Plateau area (which includes the region of the Jackpile-Paguate mines) is in the range of 75 to 140 mrem/yr, averaging about 90 mrem/yr.

#### 2.5.1.3 Human Body Burden

The radionuclide content of the human body (body burden) results from ingestion and inhalation of materials containing radioisotopes, such as those of lead, polonium, bismuth, radium, potassium, carbon, hydrogen, uranium, thorium, and several cosmogenic radionuclides. The average dose-rate equivalent from these radionuclides is 25 to 30 mrem/yr to the gonads, 125 to 1000 mrem/yr to the lungs, 50 to 100 mrem/yr to the bone, and 25 to 50 mrem/yr to bone marrow and to the gastrointestinal tract. The range in the dose-rate equivalent reflects individual habits of ingestion and inhalation and variability in the background airborne concentration of the radionuclides.

#### 2.5.1.4 Pre-Mining Environment

The pre-mining radiation environment of the Jackpile-Paguate mine site was never extensively measured. The available data are insufficient to determine the radionuclide concentrations in soil or water before mining began. It can be surmised, however, that because of the presence of uranium deposits, the radiation level in the mine area was higher than in the rest of the region. Indeed, detection of the elevated gamma radiation intensity from the Jackpile formation outcrops was responsible for the discovery of the uranium deposits. The region of elevated gamma activity before mining is shown in Figure 2.22.

Weathered material from the Jackpile formation outcrops was deposited in the channel of the Rio Paguate. The average uranium content (ore quality) of two samples collected from the outcroppings was about 0.911% $U_3O_8$ (Anaconda 1980). At a distance of about 15 m (50 ft) from the exposed ore zone the uranium content was reduced to about 0.25%. The Woodrow deposit was a highly mineralized ore and contained up to 20% $U_3O_8$. Because of weathering and surface erosion, the outcrops were natural sources of elevated concentrations of uranium in both surface soil and water. However, the only data available are those related to exploration and logging of the area for uranium mining.

### 2.5.2 Background Radiation Environment

The present background radiation environment of the Jackpile-Paguate mines includes contributions from natural radiation, from other mining and milling activities in the region,* and from fallout due to atmospheric testing of nuclear weapons.

Data on current background radiation in the area have been collected by the U.S. Environmental Protection Agency (Eadie et al. 1979) and, for a short period, by Argonne National Laboratory (ANL 1980).

#### 2.5.2.1 Radionuclides in the Soil

Average specific activities (pCi/g) of Ra-226 in the top 5 cm of soil collected at Laguna, Bibo, and Mesita (Fig. 1.1) are, respectively, 0.62 ± 0.15, 0.86 ± 0.18, 0.78 ± 0.17, pCi/g (the errors are two standard deviations of counting statistics). Across the region, the range of background specific activity of Ra-226 in soil is 0.1 to 1.9 pCi/g (Anaconda 1982). The specific activity of U-238 is about 1 pCi/g in the shales and less than 1 pCi in Tres Hermanos sandstone. The average specific activity of U-238 in soil in the United States is about 0.6 pCi/g (Lowder et al. 1964).

#### 2.5.2.2 Radionuclides in Potable Groundwater

The concentrations of uranium (U-238, U-235, and U-234) and of Ra-226 gross alpha and beta activity in samples of water from four wells on the Laguna Indian Reservation are listed in Table 2.5. The average concentrations of the

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*The L-Bar, Sohio, St. Anthony, and Windwhip mines are also located in the region.

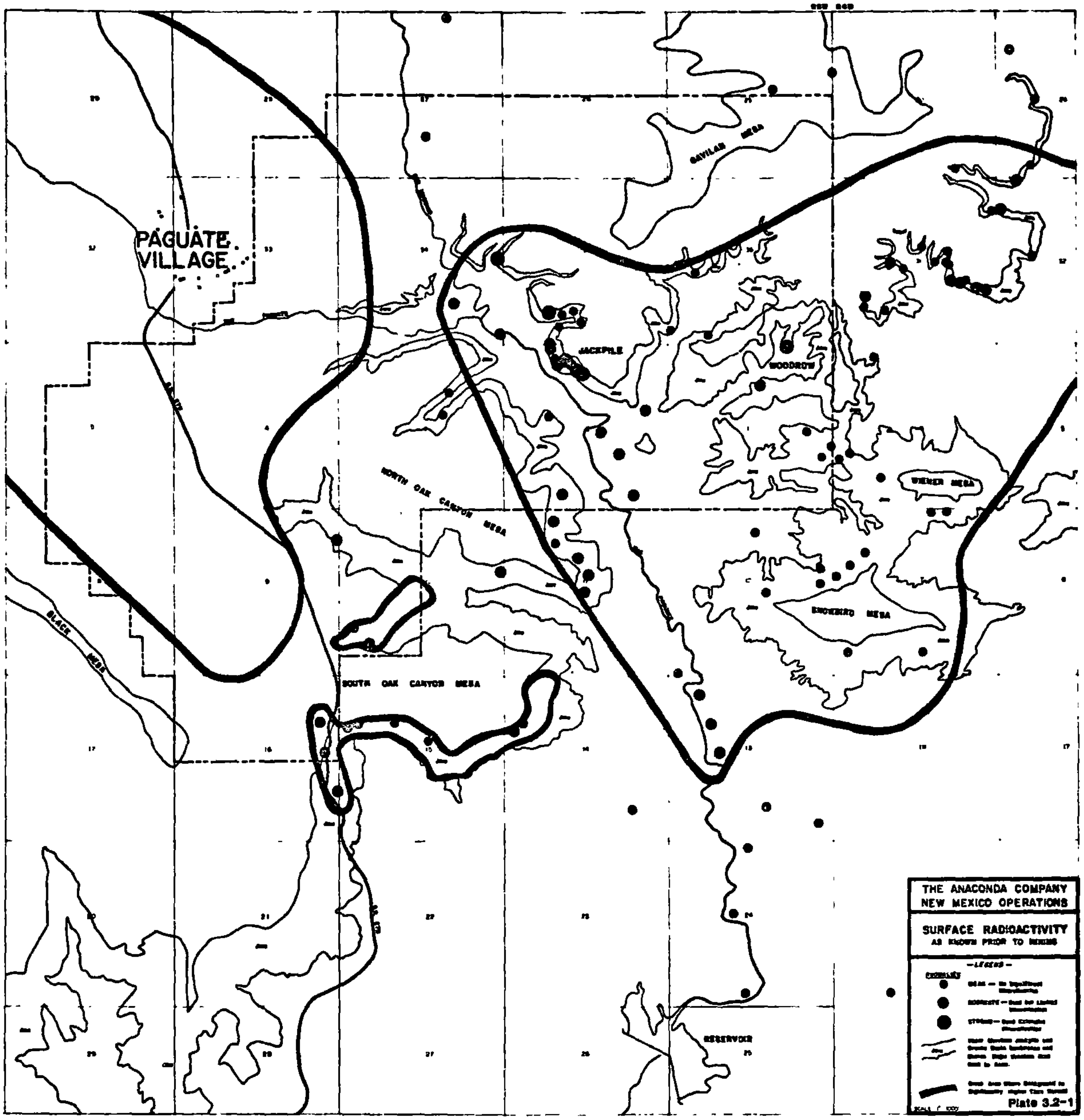


Figure 2.22. Map Showing Region of Elevated Surface Radioactivity before Mining of the Jackpile-Paguate Complex. [Broad borders delineate gross areas where background was "significantly" higher than normal." Largest dark dots designate locations where surface radioactivity was strong, indicating "good extensive mineralization;" medium-sized dots designate locations of moderate radioactivity ("good but limited mineralization"); and smallest dots designate locations of weak radioactivity ("no significant mineralization").] (From Anaconda 1980.)

Table 2.5. Concentration of Radionuclides in Groundwater from Four Wells on the Laguna Indian Reservation†[1,2]

| Well | Property Analyzed | Concentration (pCi/L ± SE)†[3] |
|---|---|---|
| Mesita #1 (BIA) | Gross Alpha | 5 ± 6 |
| | Gross Beta | 5 ± 5 |
| | Ra-226 | 0.2 ± 0.1 |
| | U-234 | 1.3 ± 0.8 |
| | U-235 | 0.4 ± 0.4 |
| | U-238 | 1.3 ± 1.0 |
| N.Y. #1 | Gross Alpha | 3 ± 5 |
| | Gross Beta | 7 ± 5 |
| | Ra-226 | 0.3 ± 0.1 |
| | U-234 | 0.5 ± 0.3 |
| | U-235 | 0.0 ± 0.2 |
| | U-238 | 0.9 ± 0.4 |
| Well #1 Paguate | Gross Alpha | 3 ± 5 |
| | Gross Beta | 3 ± 5 |
| | Ra-226 | 0.4 ± 0.1 |
| | U-234 | 0.1 ± 0.2 |
| | U-235 | 0.1 ± 0.1 |
| | U-238 | 0.1 ± 0.2 |
| Well #2 Paguate | Gross Alpha | 0 ± 7 |
| | Gross Beta | 2 ± 4 |
| | Ra-226 | 0.2 ± 0.2 |
| | U-234 | -0.3 ± 0.5 |
| | U-235 | 0.0 ± 0.2 |
| | U-238 | 0.0 ± 0.2 |

†[1] Based on unpublished data provided by M.E. Nelson, U.S. Department of Interior.

†[2] The national standards for community water systems are 5 pCi/L for radium (40 CFR Parts 100 to 399), $4 \times 10^4$ pCi/L for U-238, and $3 \times 10^4$ pCi/L for U-235 and U-234 (10 CFR Parts 0 to 199).

†[3] SE = standard error of measurement.

radionuclides for these wells are 0.3 pCi Ra-226/g, 0.4 pCi U-234/g, 0.1 pCi U-235/g, and 0.6 pCi U-238/g. These concentrations are within drinking water standards* and are typical of values reported for public water supplies in the United States. In a recent work, Kriege and Hahne (1982) surveyed Ra-226 concentrations in community water supplies in 625 towns in Iowa. The range of average concentrations was from 0.1 to 48 pCi Ra-226/L. In an earlier study (Hursh 1953), the range across the nation was found to be from 0.09 pCi Ra-226/L in raw water and 0.08 pCi/L in tap water in Los Angeles, California, to 65.4 pCi Ra-226/L in raw water and 57.9 pCi/L in tap water in Joliet, Illinois.

#### 2.5.2.3 Airborne Concentration of Particulates

Average concentrations of airborne radionuclides (Ra-226, Th-230, U-238) in composited monthly samples as determined by Eadie et al. (1979) are given in Table 2.6. The average background concentrations of airborne particulates for the area around Grants, New Mexico, about 65 km (40 mi) west of the Jackpile-Paguate mines, is reported as 25.0 $\mu g/m^3$, with radionuclide concentrations of $1.2 \times 10^{-3}$ pCi U-238/$m^3$, $1.7 \times 10^{-3}$ pCi Th-230/$m^3$, $7.5 \times 10^{-4}$ pCi Ra-226/$m^3$, and $1.4 \times 10^{-2}$ pCi Pb-210/$m^3$ (Momeni and Kisieleski 1980). These concentrations are about one order of magnitude larger than those reported elsewhere in the United States; for example, $1.2 \times 10^{-4}$ pCi U-238/$m^3$ and $4.5 \times 10^{-5}$ pCi Th-230/$m^3$ for the Chicago area (Sedlet et al. 1973), $4 \times 10^{-4}$ pCi U-238/$m^3$ for regions of New York state (McEachern et al. 1971), and $0.8 \times 10^{-4}$ pCi U-238/$m^3$ in New York City (Eisenbud and Petrow 1964).

#### 2.5.2.4 Airborne Concentration of Radon and Working Level

Average airborne concentrations of radon (Rn-222) at selected locations away from the Jackpile-Paguate mines are given in Table 2.7. The average background concentration for the Grants mining district is $4.08 \times 10^2$ pCi Rn-222/$m^3$, with seasonal variations from $2.47 \times 10^2$ pCi/$m^3$ in the summer to $6.29 \times 10^2$ pCi/$m^3$ in the winter (Momeni et al. 1979).

The average background outdoor working level (WL)** for the Grants mining district is 3.6 mWL, with a season variation from 2.5 mWL in the summer and spring to 4.9 mWL in the fall (Momeni et al. 1979).

#### 2.5.3.5 Gamma Exposure Rate

The gamma exposure rates measured by use of a high-pressure ion-chamber have been reported as 11.5 μR/hr at Laguna, 14.3 μR/hr at Bibo, 11.5 μR/hr at Mesita, and 11.9 μR/hr at Moquino (Eadie et al. 1979). The average of these exposure rates is 12.3 μR/hr.

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*The national standards for community water systems are 5 pCi/L for radium (40 CFR Parts 100 to 399), $4 \times 10^4$ pCi/L for U-238, and $3 \times 10^4$ pCi/L for U-235 and U-234 (10 CFR Parts 0 to 199).

**One "working-level" (WL) is defined as any combination of short-lived radon decay products in one liter of air that will result in the ultimate emission of $1.3 \times 10^5$ MeV of alpha energy. Under secular radioactive equilibrium with Po-218, Pb-214, and Bi-214, 100 pCi Rn-222/L would produce one working level.

Table 2.6. Average Airborne Concentrations (pCi/m$^3$) of Uranium (U-238), Thorium (Th-230), and Radium (Ra-226) in Composited Monthly Samples in the Mine Area

| Location | U-238 | Th-230 | Ra-226 |
|---|---|---|---|
| Bibo | $4.0 \times 10^{-4}$ | $3.2 \times 10^{-4}$ | $2.0 \times 10^{-4}$ |
| Mesita | $3.2 \times 10^{-4}$ | $1.8 \times 10^{-4}$ | $3.4 \times 10^{-4}$ |
| Old Laguna | $2.9 \times 10^{-4}$ | $8.5 \times 10^{-5}$ | $1.7 \times 10^{-4}$ |
| Average | $3.4 \times 10^{-4}$ | $2.0 \times 10^{-4}$ | $2.4 \times 10^{-4}$ |
| Standards | | | |
| Soluble | 3 | 0.08 | 3 |
| Insoluble | 5 | 0.3 | 2 |

From Eadie et al. 1979

Table 2.7. Average Airborne Concentration of Radon-222 in Air Samples†[1]

| Location | Concentration†[2] (pCi/m$^3$) |
|---|---|
| Old Laguna | $5.1 (\pm 2.8) \times 10^2$ |
| Laguna | $5.1 (\pm 2.9) \times 10^2$ |
| Bibo | $5.0 (\pm 2.3) \times 10^2$ |
| Mesita | $4.7 (\pm 3.1) \times 10^2$ |
| Mesita | $5.5 (\pm 4.7) \times 10^2$ |
| Moquino | $5.4 (\pm 3.1) \times 10^2$ |
| Average | $5.0 (\pm 0.33) \times 10^2$ |

†[1] Based on 48-hour samples continuously collected in 30-L plastic sample bags (Edie et al. 1979).

†[2] Errors are ± 2 standard deviations of counting statistics.

## 2.6 MINE-SITE LAYOUT

The Jackpile-Paguate mining operation is located on about 3000 ha (7500 acres) of the Laguna Indian Reservation. The Jackpile ore body is 2.4 km (1.5 mi) long and more than 0.8 km (0.5 mi) wide. The Paguate ore body is 3.2 km (2 mi) long and about 0.6 km (0.4 mi) wide.

Anaconda's operations consisted both of surface and subsurface mining. Surface mining (also called open-pit mining) is a dynamic process involving continual stripping of topsoil and overburden to expose and then remove the underlying ore deposits. A trench or box cut is made through the overlying material (overburden) to expose the ore. The ore and inclusive waste (protore) are taken from the pit and stockpiled. (Fig. 2.23 shows a typical waste pile.)

Figure 2.23. Photograph of a Typical Waste Dump (Dump V) at the Mine Complex. (The Rio Moquino is in the extreme lower righthand corner of the photo.)

Often the overburden is removed from a stratum above the ore bed and is dumped into previously mined trenches or deposited on waste piles. In subsurface (or underground) mining, the ore and inclusive wastes are all relocated to the surface. Procedures that were used in the Jackpile-Paguate mining operations are detailed in the Anaconda Company's mining and reclamation plan (Dames & Moore 1977). In the context of this discussion, the inclusive wastes are not differentiated from the protore, both referring to a level of ore quality less than 0.057% $U_3O_8$. This cutoff level below which milling of the material may not be commercially profitable is not constant and depends on the market value of the uranium products.

A schematic map of the disturbed areas of the Jackpile-Paguate mine complex is shown in Figure 2.24. (A topographic map of the same area was shown in Figure 2.1.) A key to Figure 2.24 and a listing of the total surface areas and types of material at each location shown are provided in Table 2.8. A summary listing of the various disturbed areas is provided in Table 2.9. As shown in the table, the largest areas consist of open pits and waste dumps.

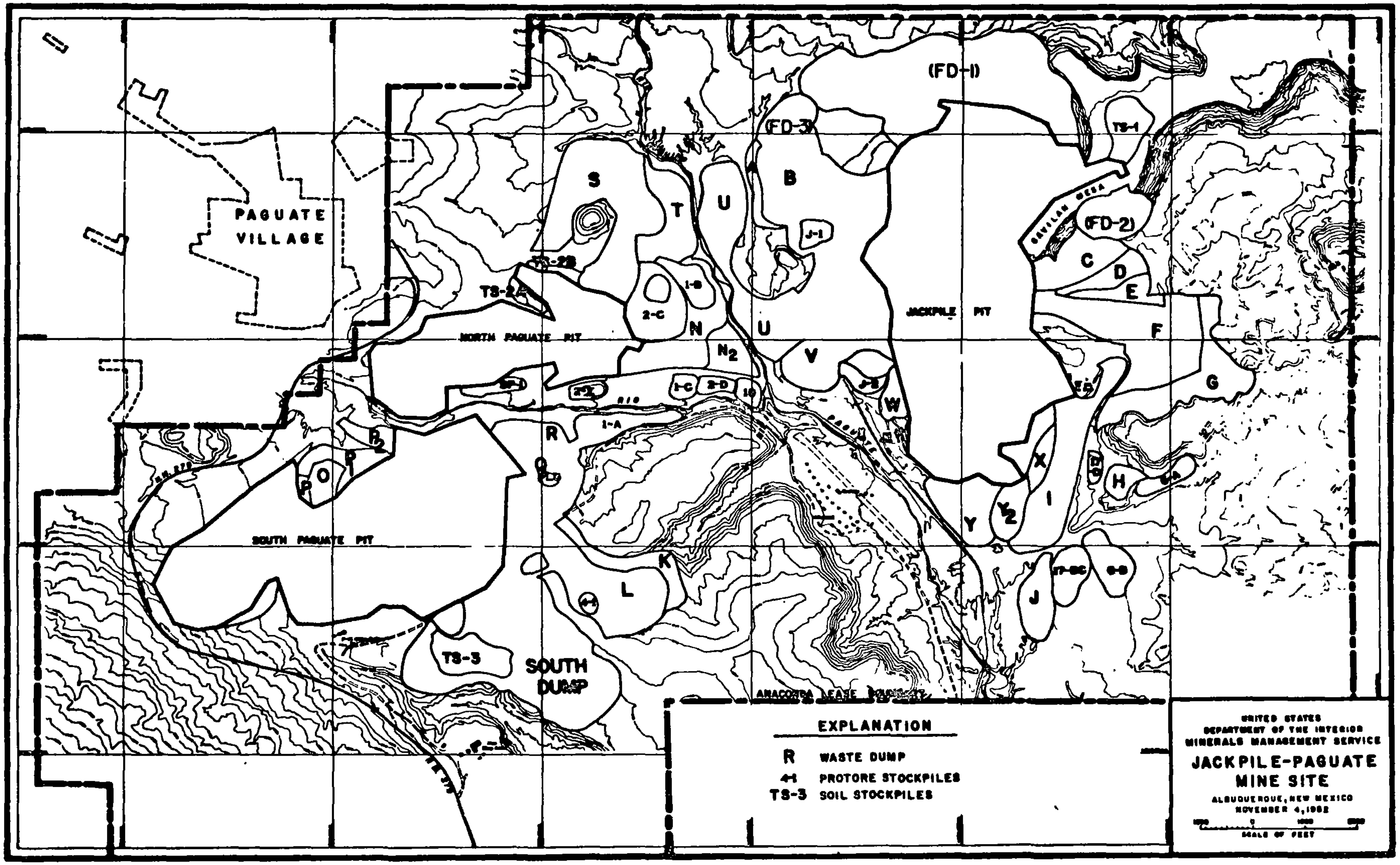


Figure 2.24. Schematic Map of Jackpile-Paguate Mine Complex. (A listing of the areal extent of and material at each site is provided in Table 2.8.)

Table 2.8. Characteristics of Disturbed Land and Surface Materials in Jackpile-Paguate Mines

| Site Designation†[1] | Area (hectares) | Type of Material on Surface or Under Topsoil†[2] |
|---|---|---|
| Dump A | 9.3 | Outer surface: mainly shales mixed with THS |
| Dump B | 28.7 | Outer surface: mainly shales mixed with THS |
| Dump C | 8.5 | Outer surface: THS mixed with some shales |
| Dump D | 5.7 | Outer surface: THS mixed with some shales |
| Dump E | 4.9 | Outer surface: THS mixed with some shales |
| Dump F | 29.5 | Upper topsoil: mainly shale with some THS and JSS |
| Dump G | 19.8 | Under topsoil: shales and JSS |
| Dump H | 2.8 | Outer surface: mainly JSS and some shales |
| Dump I | 23.1 | Under topsoil: shales mixed with JSS |
| Dump J | 6.1 | Under topsoil: mainly JSS |
| Dump K | 8.9 | Outer surface: mainly THS mixed with shales |
| Dump L | 23.5 | Under topsoil: mainly shales mixed with THS |
| Dump N | 19.4 | Outer surface: shales mixed with THS and JSS |
| Dump N2 | 6.5 | Same as N |
| Dumps O,P,P1,P2 | 14.2 | Outer surface: mainly THS with limited shales |
| Dump Q | 21.0 | Outer surface: JSS mixed with some shales |
| Dump R | 5.7 | Outer surface: shales mixed with some JSS |
| Dump S | 38.8 | Under topsoil: THS with some shales |
| Dump T | 12.9 | Under topsoil: JSS and some shales |
| Dump U | 24.7 | Outer surface: JSS and some shales |
| Dump V | 20.6 | Outer surface: JSS, shales and THS |
| Dump W | 2.8 | Outer surface: THS and shales |
| Dump X | 3.6 | Under topsoil: JSS and some shales |
| Dump Y | 12.1 | Outer surface: JSS, some shales and THS |
| Dump Y2 | 6.1 | Under topsoil: JSS and some shales |
| South Dump | 70.8 | Outer surface: shales and THS on slopes |
| FD-1 | 67.0 | Outer surface: shales with JSS and THS |
| FD-2 | 10.1 | Outer surface: shales mixed with THS |
| FD-3 | 4.0 | Outer surface: JSS, some shales and THS |
| 17BC | 6.1 | JSS |
| 6A | 6.9 | JSS |
| 6B | 3.6 | JSS |
| J1 | 3.6 | JSS |
| J2 | 3.2 | JSS |
| 17D | 1.2 | JSS (shipped to mill) |
| 1B | 3.6 | JSS |
| 2C | 4.9 | JSS |
| 10 or 10D | 1.2 | Igneous dike associated with JSS |
| 2D | 2.4 | JSS |
| 1C | 2.0 | JSS |
| 1A | 8.1 | JSS |
| 2E | 1.2 | JSS |
| SP-1 | 3.6 | JSS |
| PLG | 1.2 | JSS |
| 4-2 | 3.2 | JSS |

Table 2.8. Continued

| Site Designation†[1] | Area (hectares) | Type of Material on Surface or Under Topsoil†[2] |
|---|---|---|
| SP-2 | 4.9 | JSS |
| SP-2B | 0.8 | JSS |
| TS-1 | 8.5 | THS |
| TS-2A | 2.0 | THS |
| TS-2B | 2.4 | THS |
| TS-3 | 7.7 | THS |
| Borrow Site | 17.4 | THS |
| Jackpile Pit | | |
| • North Pit | 64.3 | Outer surface: mixed JSS and shales |
| • Central Pit | 63.9 | Outer surface: mixed JSS and shales |
| • South Pit | 63.9 | Outer surface: mixed JSS and shales |
| N. Paguate Pit | | |
| • West Pit | 19.0 | Outer surface: mixed JSS and shales |
| • Central Pit | 19.0 | Outer surface: mixed JSS and shales |
| • East Pit | 19.0 | Outer surface: mixed JSS and shales |
| S. Paguate Pit | | |
| • West Pit | 54.2 | Outer surface: mixed JSS and shales |
| • Central Pit | 53.8 | Outer surface: mixed JSS and shales |
| • East Pit | 53.8 | Outer surface: mixed JSS and shales |
| Housing | 7.7 | Outer surface: mainly THS |
| Shop | 6.9 | Outer surface: mixed JSS, shales and THS |
| Old Shop | 1.6 | Outer surface: mixed JSS, shales and THS |
| P-10 Adit Area | 1.2 | Outer surface: mixed JSS, shales and THS |
| Pit Office Area | 0.8 | Outer surface: mixed JSS, shales and THS |
| Park Lot SP1 | 3.6 | Outer surface: JSS mixed with shales |
| Park Lot SP2 | 4.9 | Outer surface: JSS mixed with shales |
| Rail Spur & Roads | 50.1 | Outer surface: mixed JSS, shales and THS |

†[1] See Figure 2.24 for map of site locations.

†[2] THS--Tres Hermanos Sandstone; JSS--Jackpile Sandstone.

Based on information provided by Anaconda Minerals Co.

Table 2.9. Summary of Surface Area of Excavated and Disturbed Areas on Jackpile-Paguate Mine Complex

| Location | Area (hectares) |
|---|---|
| Open Pit Areas Excavated | |
| Jackpile | 192 |
| North Paguate | 57 |
| South Paguate | 160 |
| | 409 |
| Waste Dumps | |
| Jackpile area dumps | 290 |
| North Paguate area dumps | 77 |
| South Paguate area dumps | 144 |
| | 511 |
| Topsoil Stockpiles on Natural Ground | |
| TS-1 | 8.5 |
| TS-2 | 4.5 |
| | 13 |
| Ore and Protore Stockpiles on Natural Ground | |
| Jackpile area piles | 30 |
| North Paguate area piles | 18 |
| South Paguate area piles | 14 |
| | 62 |
| Other Features on Natural Ground | |
| General area disturbance (includes buildings, etc.) | 27 |
| Roads | 36 |
| Rail spur and miscellaneous areas | 15 |
| | 78 |
| TOTAL | 1073 |

Modified from Anaconda Co. (1980).

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# 3. ANALYSIS OF PATHWAYS OF EXPOSURE

## 3.1 INTRODUCTION

Although mining activity at the Jackpile-Paguate complex has stopped, humans continue to be exposed to the radioactive materials remaining on the site. The magnitude of future exposure from these sources will depend upon the degree to which the reclamation procedures that are implemented will prevent release of radioactivity to the principal pathways of migration--the atmosphere and the hydrosphere.

There are two basic types of radiation exposure--internal and external. Internal exposure results from inhalation of airborne radionuclides and ingestion of contaminated food and water, and external exposure results from exposure to gamma and beta radiations emitted, for example, from airborne materials, from surfaces of ore and waste remaining on the site, and from the airborne radionuclides deposited on the ground (Fig. 3.1).

The principal mechanisms for release of radioactivity into the atmosphere from the disturbed mine sites are fugitive dusting of the materials from the surface and exhalation of radon through the surface cover. Inhalation of the airborne radionuclides by humans results in irradiation of the lungs and other organs. Deposition of airborne materials on soil and forage contributes to the contamination of food (in this case, meat from livestock grazed on contaminated forage). Additionally, the airborne radionuclides are a source of direct gamma radiation.

Groundwater can become contaminated from percolation of precipitation through the waste piles and from recharge by contaminated surface water. Contamination of surface water can result from seepage of contaminated groundwater into the surface water and by runoff of precipitation that has fallen on waste piles and other contaminated surfaces. Other potential sources of contamination are ponding of groundwater within the mine pits and collection of rainwater behind the blocked arroyos on the site (Sec. 2.3).

A schematic diagram showing possible pathways for contamination of water passing through the site is presented in Figure 3.2. Such contaminated water can contribute to human radiation exposure both directly (e.g., ingestion of contaminated drinking water by humans) and indirectly (e.g., ingestion of contaminated water by livestock subsequently consumed by humans).

Under the no-action decommissioning alternative (Alternative A, as described in Appendix A), there would be no reclamation of the site, and mining could be resumed in the future. The subgrade ores and wastes would remain on the site, and open-pit mines would not be backfilled. Thus, even though public access to the site would be controlled, atmospheric and hydrospheric transport of radioactive material beyond the site boundary would continue. Grazing of

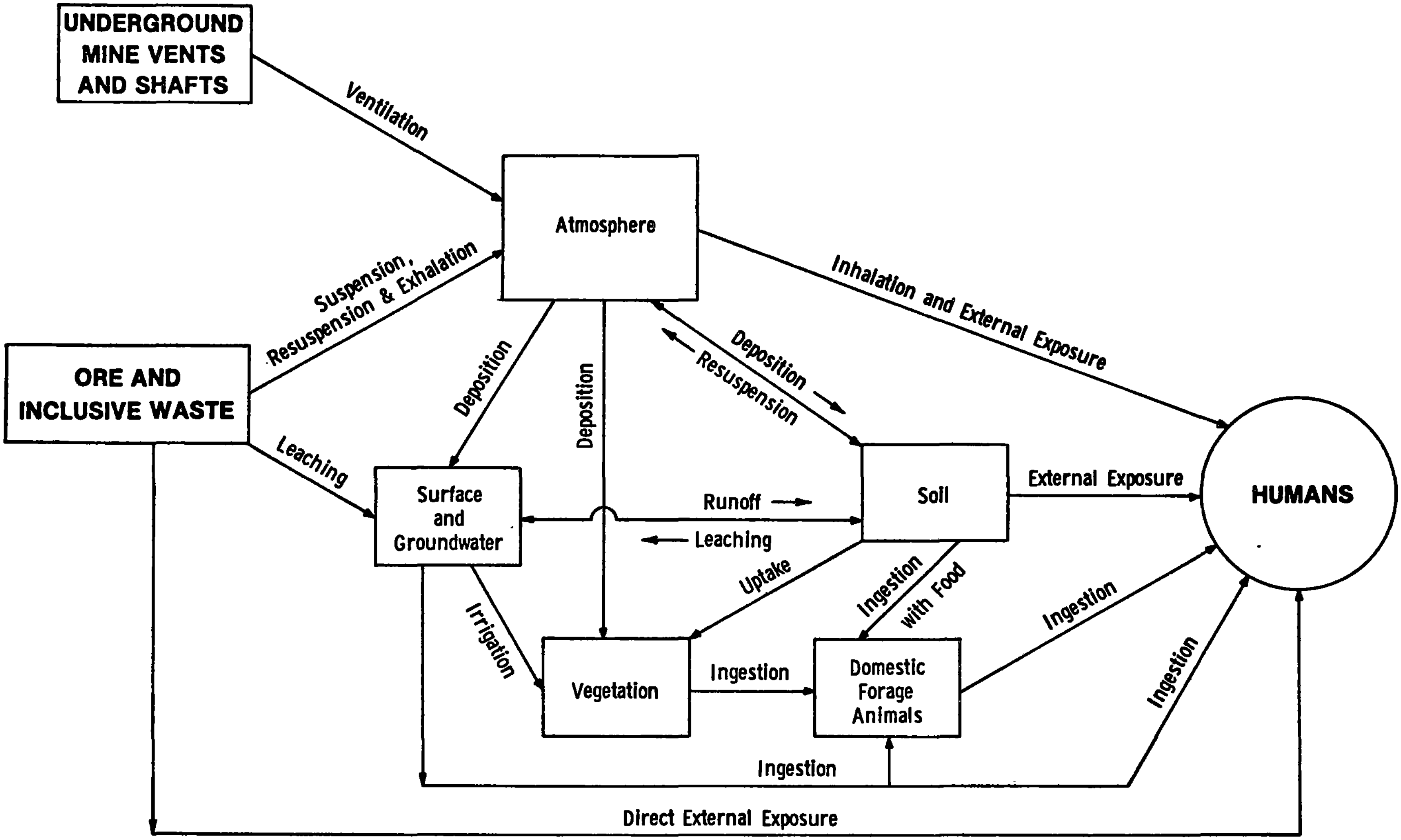



Figure 3.1. Sources of Radioactive Effluents from the Mines and Exposure Pathways to Humans. (In the analysis of pathways of exposure, each of the sources and routes of transport of radioactivity depicted in this figure was considered.)

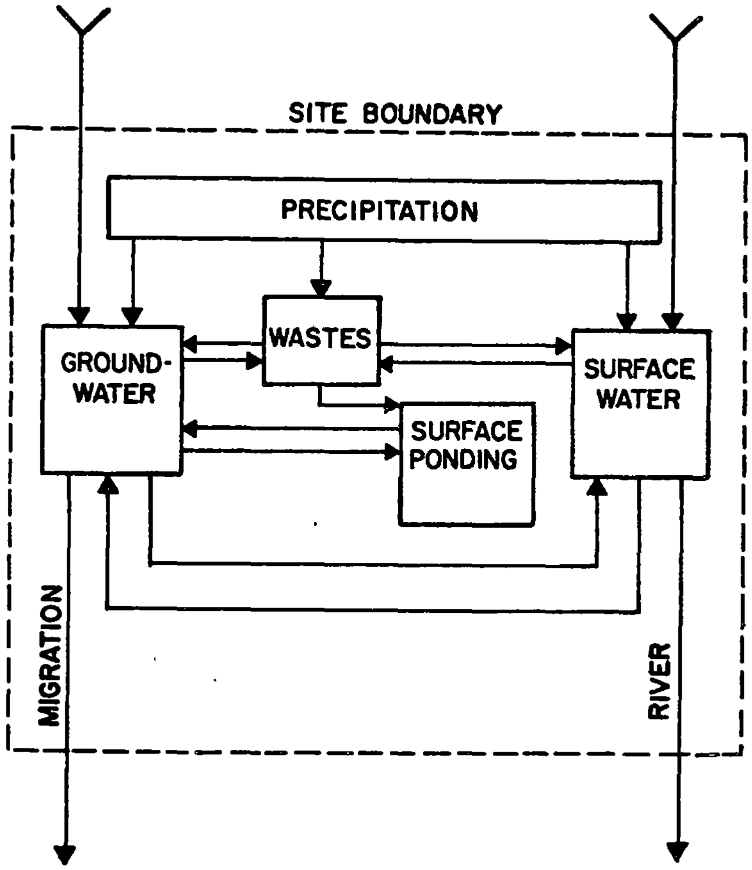



Figure 3.2. Schematic Diagram of Contamination of Water Passing through the Mine Site. (The arrows from outside of the site boundary represent surface water and groundwater entering the mine site. All of the routes of hydrological transport depicted in this figure were examined.)

livestock on the site would not be permitted under the no-action case, but ground deposition of airborne material on grazing lands beyond the boundaries would not diminish. Under all other alternatives except Alternative B, the open pits would be backfilled, and the disturbed surfaces and waste piles would be covered with a layer of soil. The processes of fugitive dusting and surface runoff of radioactive materials would thus be controlled, and the potential for human exposure reduced.

Analyses of the potential radiological exposures after implementation of the alternative methods of decommissioning are summarized in this chapter. The discussion of exposure pathways is divided into two sections--Atmospheric (Sec. 3.2) and Hydrologic (Sec. 3.3). Radiation doses are discussed in Section 3.4, and population dose commitments in Section 3.5. The elements of analysis are outlined schematically in Figure 3.3. More detailed discussions of analyses and/or more detailed results are presented in Appendices B through D.

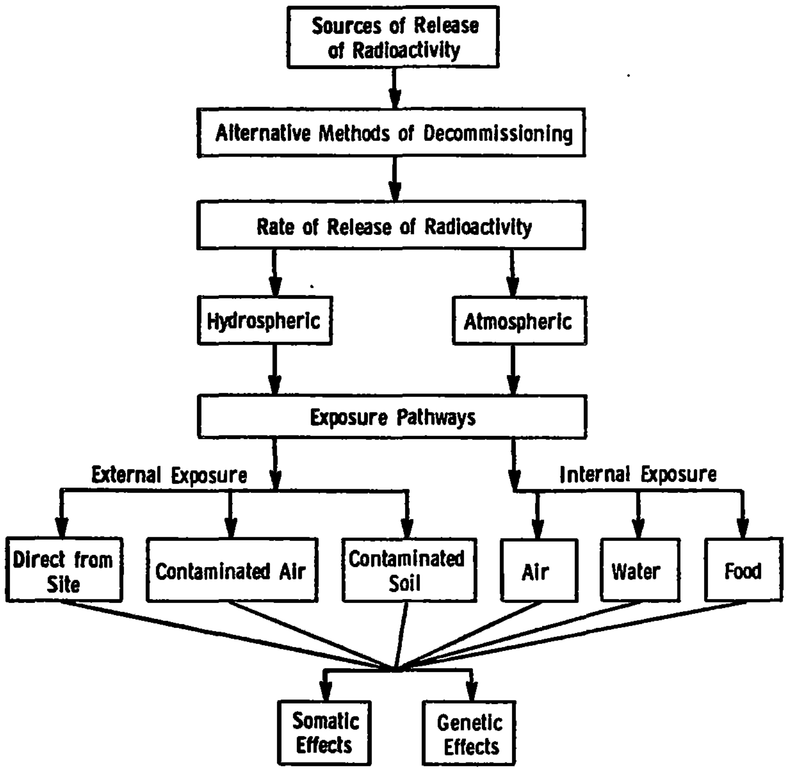



Figure 3.3. Elements of Analysis of Radiological Impacts Resulting from Selection of Alternative Methods of Decommissioning of the Jackpile-Paguate Mine Complex.

Radionuclides in the uranium-238 decay series are the primary sources of radioactivity from the residual material at the mine complex. The specific radionuclides of concern relative to exposure of humans are uranium (U-238, U-234), thorium (Th-230), radium (Ra-226), lead (Pb-210), polonium (Po-210), and radon (Rn-222). The concentrations of the radionuclides in the U-235 decay series and the Th-232 decay series are small in comparison with those in the U-238 series and thus are not considered here.

In these analyses, mineralized materials on the site are considered in two categories: (1) protore (material containing more than 0.02% equivalent $U_3O_8$)

and (2) radioactive materials* (material containing more than 5 pCi/g of any of the radionuclides in the uranium series). In materials that are not mineralized (i.e., contain activity less than 5 pCi/g of any of the radionuclides), such as overburden, the concentrations of radionuclides are comparable to those in natural soil in areas adjacent to the mine complex.

## 3.2 ATMOSPHERIC PATHWAYS

### 3.2.1 Introduction

Analysis of the atmospheric pathways of exposure for each of the suggested decommissioning alternatives includes characterization of the sources of atmospheric release, estimation of the rates of release of particulates (U-238, Th-230, Ra-226, Pb-210, Po-210) and of radon (Rn-222), and calculation of airborne concentrations and surface activities of the radionuclides.

The analyses summarized here are based on a review of data obtained from the Anaconda Company, the Department of the Interior, an aerial gamma survey of the mine site by EG&G, and other published data and resources. The Argonne National Laboratory Uranium Dosimetry and Dispersion (UDAD) computer code (Momeni et al. 1979) was used for the calculations. For comparison, the airborne concentrations of radon were also calculated using the U.S. Environmental Protection Agency's Industrial Source Complex (ISC) Code (USEPA 1979).

### 3.2.2 Characterization of the Sources of Atmospheric Release

Characteristics of disturbed land and surface materials at the Jackpile-Paguate mines were described in Section 2.6. The specific activity of uranium measured in composite samples collected from each disturbed mine area and the surface area of each are listed in Table 3.1.**

The total surface area of the indentified disturbed lands is 1132 ha (2797 ac). The average specific activity of uranium in the Jackpile sandstone materials remaining on the mine site is about 70 pCi/g, and the average specific activity of uranium in the materials obtained from Tres Hermanos sandstone is about

*The term "radioactive material" often is used in a broad sense to refer to those materials containing radioactivity in excess of that occurring in the natural environment of a region. In these analyses, however, the term is used in reference to those materials containing a specific activity in excess of the EPA's proposed limit of 5 pCi Ra-226/g (USEPA 1982).

**The average specific activity of each of the other radionuclides in the uranium decay series (U-234, Th-230, Ra-226, Pb-210, and Po-210) in most of the samples collected from the Jackpile sandstone was about the same as that of U-238 (Momeni 1981, 1982a, 1982b). Thus, we assumed that these radionuclides were in secular radioactive equilibrium in the Jackpile sandstone.

Table 3.1. Areal Extent, Activity†[1] of Uranium, and Rates of Radon Release from the Surface of Source Locations

| Site†[2] | Area (hectares) | Specific Activity (pCi U-238/g) | Radon Release Rate†[3] (Ci/yr) |
|---|---|---|---|
| Dump A | 9.3 | 1.6 | 2.3 |
| Dump B | 28.7 | 1.0 | 4.5 |
| Dump C | 8.5 | 0.9 | 1.2 |
| Dump D | 5.7 | 1.4 | 1.3 |
| Dump E | 4.9 | 0.5 | 0.4 |
| Dump F | 29.5 | 1.4 | 6.5 |
| Dump G | 19.8 | 2.0 | 6.2 |
| Dump H | 2.8 | 49.7 | 21.9 |
| Dump I | 23.1 | 3.5 | 12.7 |
| Dump J | 6.1 | 3.6 | 3.5 |
| Dump K | 8.9 | 6.9 | 9.7 |
| Dump L | 23.5 | 1.9 | 7.0 |
| Dump N | 19.4 | 15.0 | 45.9 |
| Dump N2* | 6.5 | 75.0 | 76.9 |
| Dump O,P,P1,P2 | 14.2 | 1.6 | 3.6 |
| Dump Q* | 21.0 | 60.0 | 198.7 |
| Dump R | 5.7 | 4.0 | 3.6 |
| Dump S | 38.8 | 1.0 | 6.1 |
| Dump T | 12.9 | 1.4 | 2.8 |
| Dump U | 24.7 | 11.6 | 45.2 |
| Dump V | 20.6 | 4.7 | 15.3 |
| Dump W | 2.8 | 0.9 | 0.4 |
| Dump X | 3.6 | 6.5 | 3.7 |
| Dump Y | 12.1 | 11.3 | 21.6 |
| Dump Y2 | 6.1 | 1.5 | 1.4 |
| South Dump | 70.8 | 1.8 | 20.1 |
| FD-1 | 67.0 | 1.0 | 10.6 |
| FD-2 | 10.0 | 16.0 | 25.2 |
| FD-3 | 4.0 | 5.0 | 3.2 |
| 17BC* | 6.1 | 75.0 | 72.1 |

Table 3.1. Continued

| Site†2 | Area (hectares) | Specific Activity (pCi U-238/g) | Radon Release Rate†3 (Ci/yr) |
|---|---|---|---|
| 6A* | 6.9 | 70.0 | 76.1 |
| 6B | 3.6 | 46.5 | 26.4 |
| J1 | 3.6 | 33.5 | 19.0 |
| J2* | 3.2 | 175.0 | 88.3 |
| 17D* | 1.2 | 185.0 | 35.0 |
| 1B | 3.6 | 50.0 | 28.4 |
| 2C | 4.9 | 39.5 | 30.5 |
| 10* | 1.2 | 140.0 | 26.5 |
| 2D* | 2.4 | 65.0 | 24.6 |
| 1C | 2.0 | 22.0 | 6.9 |
| 1A | 8.1 | 11.0 | 14.0 |
| 2E* | 1.2 | 80.0 | 15.1 |
| SP-1 | 3.6 | 47.5 | 27.0 |
| PLG | 1.2 | 1.8 | 0.3 |
| 4-2 | 3.2 | 27.5 | 13.9 |
| SP-2* | 4.9 | 65.0 | 50.2 |
| SP-2B* | 0.8 | 220.0 | 27.8 |
| TS-1 | 8.5 | 1.8 | 2.4 |
| TS-2A | 2.0 | 1.8 | 0.6 |
| TS-2B | 2.4 | 1.1 | 0.4 |
| TS-3 | 7.7 | 1.3 | 1.6 |
| Topsoil Borrow | 17.4 | 1.5 | 4.1 |
| Jackpile Pit | | | |
| North | 64.3 | 10.0 | 101.3 |
| Central* | 63.9 | 65.0 | 654.9 |
| South* | 63.9 | 270.0 | 2720.4 |
| North Paguate Pit | | | |
| West | 19.0 | 16.3 | 48.8 |
| Central | 19.0 | 19.0 | 56.9 |
| East | 18.6 | 30.5 | 89.5 |
| South Paguate Pit | | | |
| West | 54.2 | 1.6 | 13.7 |
| Central | 53.8 | 6.5 | 55.1 |

Table 3.1. Continued

| Site†[2] | Area (hectares) | Specific Activity (pCi U-238/g) | Radon Release Rate†[3] (Ci/yr) |
|---|---|---|---|
| East | 53.8 | 8.5 | 72.1 |
| Housing | 7.6 | 3.0 | 3.6 |
| Shop | 6.8 | 8.5 | 9.1 |
| Old Shop | 1.6 | 13.5 | 3.4 |
| P-10 Adit Area | 1.2 | 43.0 | 8.1 |
| Pit Office | 0.8 | 11.0 | 1.4 |
| Parking Lot at SP-1 | 2.8 | 20.0 | 8.8 |
| Parking Lot at SP-2 | 4.8 | 12.5 | 9.5 |
| Rail Spur | 50.0 | 65.0 | 512.5 |
| Roads | 35.2 | 11.9 | 66.0 |
| Total | 1132 | | 5587.8 |

†[1] The data on specific activity and surface areas were provided by Anaconda Minerals Company. The data do not include the ore piles and protore intended for shipment to Anaconda's mill for processing.

†[2] Sites identified with an asterisk ("*") are classified in this report as consisting of protore [material containing $U_3O_8$ in concentrations exceeding 0.02% (55 pCi U-238/g)]. Locations of sites are shown in Figure 2.24.

†[3] Based on a specific flux of (0.5 pCi/m$^2$·sec Rn-222)/(pCi Ra-226/g).

1.5 pCi/g.* The specific activity of materials consisting mainly of shales mixed with some Tres Hermanos sandstone is about the same as Tres Hermanos sandstone alone. Data indicate that the only material with a specific activity of uranium exceeding that of natural background is the Jackpile sandstone. The specific activity of waste piles that consist of mixtures of Jackpile sandstone and the other, nonmineralized materials is more variable than the specific activity of those waste piles consisting of Tres Hermanos sandstone and shale mixtures.

For the purpose of analysis, the mine complex was divided into three groups of emission sources: Jackpile source, wastepile source, and Paguate source.

*Calculated on the basis of the average specific activity and the surface area of each of the individual types of mine waste. Calculation of the total average specific activity for the mine wastes on the basis of the volume and individual specific activity of each type of waste material is not readily feasible because neither the total volume nor the specific activity is known. The specific activities of the composite samples may be in error by as much as a factor of two.

Each group was then geographically subdivided into subgroups: north and south Jackpile, north and south Paguate, and north, east, southeast, and south waste piles.* The boundaries of these subgroups are shown in Figure 3.4. The Jackpile and Paguate source groups do not consist exclusively of pits, they also include adjacent waste dumps. It was assumed that there would be secular radioactive equilibrium of the radionuclides in the soil and ore; therefore, the average specific activity of U-238 at each site is considered equivalent to the specific activity of U-234, Th-230, Ra-226, Pb-210, and Po-210.

### 3.2.3 Rate of Release of Radioactivity into the Atmosphere

The annual rates of release of particulates and radon into the atmosphere from each subgroup source of emissions were calculated for each decommissioning alternative.

#### 3.2.3.1 Particulates

Alternative A

Under Alternative A (No-Action Case), a protective soil cover would not be placed on the disturbed surfaces, and wind erosion of exposed radioactive materials would continue. The rates of release of particulates into the atmosphere calculated for these conditions are given in Table 3.2. These rates were calculated from wind erosion formulation incorporated in the UDAD code (Momeni et al. 1979).

Alternatives B-D

Because the mine site is located in an arid region with sparse natural vegetation, the surfaces are subject to dusting and wind erosion. Covering of the radioactive surfaces on the mine site with soil as would be done under Alternatives B through D would not eliminate wind erosion, but such erosion would not be expected to result in atmospheric release of radioactive materials from the mine site as long as the integrity of the protective surfaces was maintained. Thus, in these analyses, radioactive particulate releases have been estimated only for Alternative A.

#### 3.2.3.2 Radon

Alternative A

The calculated average rates of release of radon from each of the subgroup sources of emission are listed in Table 3.3. These values are based on an average specific flux of 0.5 (pCi Rn-222/$m^2$·sec)/(pCi Ra-226/g). The total rate of release of radon from the mine site is calculated at 5586 Ci Rn-222/yr. Of the total rate of release of radon, 3915 Ci/yr (70%) is released from materials classified as protore (Table 3.1), 1382 Ci/yr (25%) from materials

*The area of each subgroup is equivalent to the area of the individual waste piles. For example, waste piles H and GA are included in the southeast dump subgroup (Fig. 3.4), even though they are outside of the squared boundary.

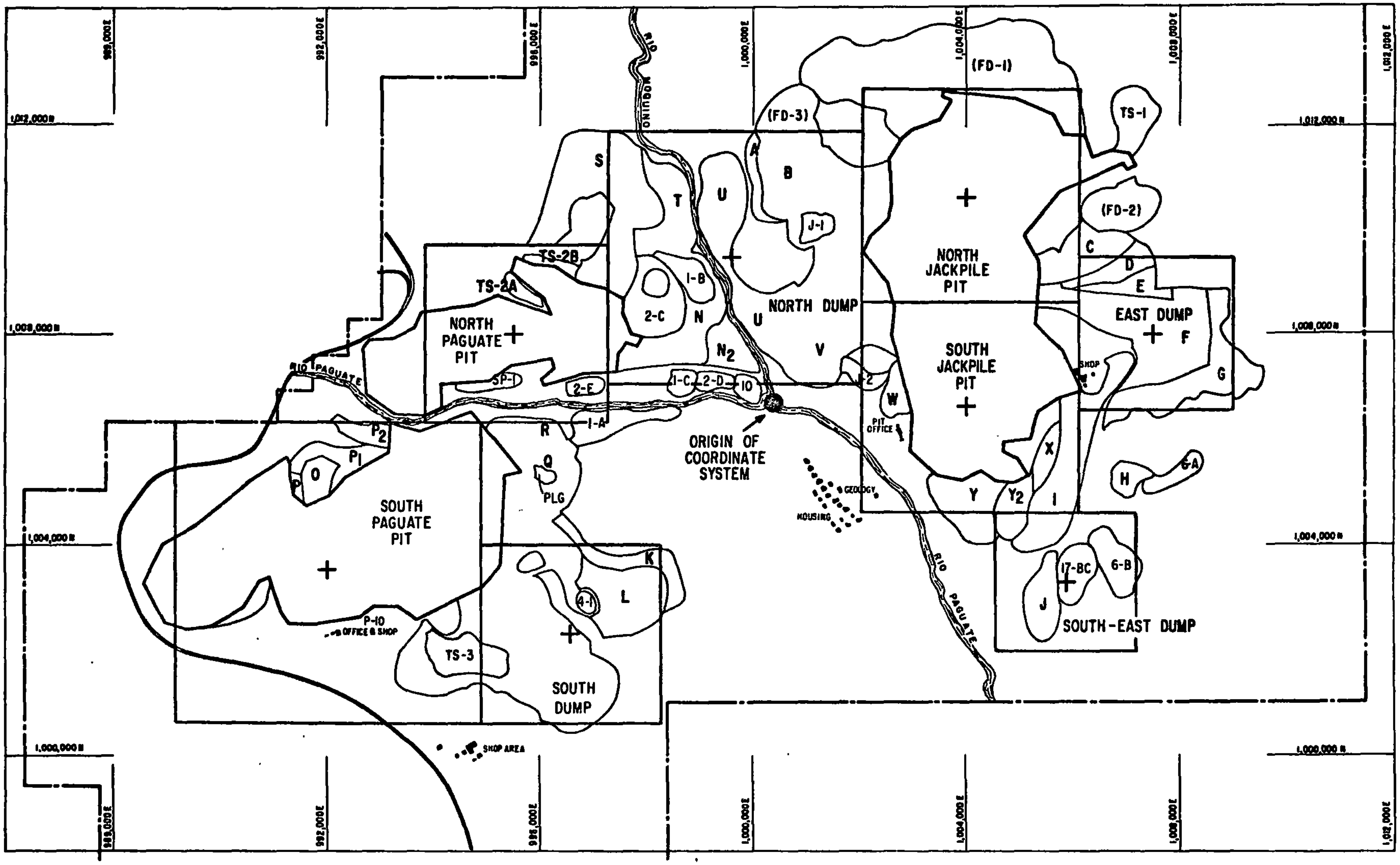





Figure 3.4. Boundaries and Centers of Subgroup Sources of Atmospheric Emissions. (The center of each source subgroup is designated by a "+".)

Table 3.2. Average Rate of Release of Particulates into Atmosphere under Decommissioning Alternative A

| Subgroup†[1] | Area (hectares)†[2] | Release Rate†[3] (Ci/yr) | Percentage of Total Rate |
|---|---|---|---|
| North Jackpile | 105 | 0.38 | 36.4 |
| South Jackpile | 105 | 0.38 | 36.4 |
| North Paguate | 90 | 0.067 | 4.6 |
| South Pagute | 210 | 0.063 | 11.5 |
| North Waste Dump | 245 | 0.068 | 5.8 |
| East Waste Dump | 80 | 0.017 | 1.8 |
| Southeast Waste Dump | 60 | 0.044 | 1.3 |
| South Dump | 95 | 0.005 | 2.3 |

†[1] See Figure 3.4 for locations.

†[2] 1 hectare = $1 \times 10^4$ $m^2$

†[3] For each of the radionuclides U-238, U-234, Th-230, Ra-226, Pb-210, and Po-210.

Table 3.3. Estimated Rate of Release†[1] of Radon (Ci Rn-222/year) from Each Subgroup Source of Emissions for Decommissioning Alternatives A and B

| Subgroup | Alternative A | Alternative B |
|---|---|---|
| North Jackpile | 2073 | 1223 |
| South Jackpile | 2073 | 1223 |
| North Paguate | 365 | 215 |
| South Paguate | 344 | 203 |
| North Waste Dump | 369 | 218 |
| East Waste Dump | 94 | 55 |
| Southeast Waste Dump | 244 | 144 |
| South Waste Dump | 26 | 15 |
| Total | 5588 | 3296 |

†[1] Based on specific flux of $\phi_s$ = (0.5 pCi Rn-222/$m^2\cdot$sec)/(pCi Ra-226/g).

classified as radioactive but less so than protore, and the remainder (5%) from soil, with specific activities of less than 5 pCi U-238/g. Thus, the total release rate attributable to mineralized materials (specific activity in excess of 5 pCi U-238/g) would be 5309 Ci Rn-222/yr, or 95% of the entire radon release rate.

Alternative B

Under decommissioning Alternative B, all disturbed areas would be covered with 30 cm (1 ft) of top soils. The average specific activity of these soils is about 1.5 pCi Ra-226/g (range of 0.1 to 1.9 pCi/g). After decommissioning, the total radon release rate from the site would be about 3296 Ci/yr above the release rates from natural background (Table 3.3). As shown, the 30 cm of soil cover would reduce radon flux values to 59% of those calculated for Alternative A.

Alternatives C1-D

Under Alternatives C1 through D, a total of 150 cm (5 ft) of soil would be placed over all mineralized materials containing an average specific activity of U-238 in excess of 5 pCi/g (protore, waste piles containing Jackpile sandstone on their outer surface, and open pits). Similar to Alternative B, all the other disturbed areas would be covered with 30 cm (1 ft) of topsoil.

A surface soil cover of 150 cm would reduce radon flux to 7% of the flux from uncovered protores. Since 95% of radon released from the entire mine site (5309 Ci/yr) is released from the mineralized materials, after reclamation the total radon release rate from these sites would decrease to 372 Ci/yr. The remaining radon released from the mine site (5588 Ci/yr - 5309 Ci/yr = 279 Ci/yr) would be reduced to 59% (165 Ci/yr). Thus, the total radon released above the natural background from the mine under each of the Alternatives C1 through D would be 444 Ci/yr (8% of the values calculated for Alternative A). Calculation of radon release rate from the pits is not readily feasible at this time since the depth of soil cover added will be determined by the groundwater recovery level (see Appendix A). However, it is surmised that after decommissioning, the depth of cover at some locations may exceed 150 cm, and the total radon release rate would be less than 8% of the Alternative A values.

### 3.2.4 Concentrations of Airborne Radionuclides

Based on the release rates specified above, airborne concentrations of particulates (U-238, Th-230, Ra-226, Pb-210, and Po-210) and radon (Rn-222 and working level) were calculated for 25 locations. These locations include towns within 80 km (50 mi) of the mine complex, four monitoring stations maintained by the Anaconda Company, and four points representing the approximate centers of four grazing ranges around the site (north, south, east, and west ranges). Results for selected locations are presented below; results for all 25 locations are given in Appendix D.

#### 3.2.4.1 Particulates

Releases of radioactive particulates would occur only under Alternative A (No-Action Case). The total concentration of particulates in air from all of the sources calculated for Alternative A conditions is given in Table 3.4 for 15 locations on and around the mine site. The concentrations listed represent composite values based on calculations of particulates released into the atmosphere from the mine site and from the resuspension of material previously deposited on the ground. The concentrations are given for the radionuclides U-238, Pb-210, and Po-210. The concentrations of U-234, Th-230, and Ra-226 each would be the same as that of U-238. The concentrations of Pb-210 are Po-210 are slightly higher than those of U-238 because of the contributions from radioactive decay of radon.

The highest concentrations of particulates listed (about $2.7 \times 10^{-3}$ pCi/m$^3$) are at the Jackpile housing, the only residential housing on the mine site. The particulate concentrations at Paguate, the nearest town to the mine site, were calculated to be about $9.7 \times 10^{-4}$ pCi/m$^3$. (A photograph of the nearest residence in Paguate to the mine is shown in Fig. 3.5.) The concentrations of airborne particulates are shown in Figure 3.6 at various distances from the confluence of Rio Paguate and Rio Moquino on the mine site. The concentrations are shown for five directions--north, east, south, west, and south-southeast. The latter is the direction of maximum transport of the particulates, as based on the concentration of radon at 20 km (12 mi). It is indicated in Figure 3.6a that for distances less than 3 km (2 mi), the concentration of U-238 is higher to the east than in the direction of maximum transport. This is due to the large surface area of the mine, the east-west orientation of the mine layout, and the fact that the emissions from the Jackpile source group are larger than those from other areas on the mine complex. Figure 3.7 shows isopleths (lines of equal concentration) of Ra-226 in air. The concentrations are expressed as logarithms of the ratio of Ra-226 concentration to the maximum permissible body burden for radium. A three-dimensional representation of these isopleths is given in Figure 3.8.

Figure 3.5. Nearest Offsite Residence to the Mine Complex, a House in the Eastern Portion of Paguate.

Table 3.4. Total Airborne Concentration (pCi/m$^3$) of Particulates, Radon, and Working Level Calculated for Alternative A Conditions†[1]

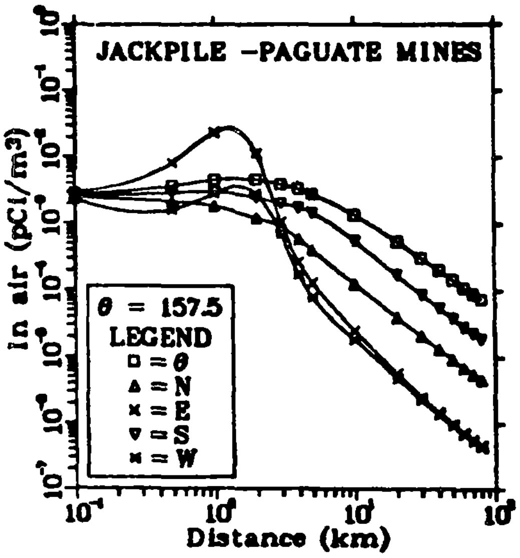
| | Location†[2] | | | | | Rn-222 | | |
|---|---|---|---|---|---|---|---|---|
| Location | X(km) | Y(km) | U-238†[3] | Pb-210 | Po-210 | UDAD | ISC | mWL†[4] |
| Bibo | -2.0 | 3.0 | 2.97E-4 | 3.45E-4 | 2.99E-4 | 3.15E+1 | 4.50E+1 | 1.97E-1 |
| Casa Blanca | -10.0 | -10.0 | 1.04E-4 | 1.73E-4 | 1.07E-4 | 4.25 | 5.55 | 3.88E-2 |
| Jackpile-Housing | 0.0 | -0.2 | 2.66E-3 | 2.67E-3 | 2.66E-3 | 1.10E+2 | 1.89E+2 | 3.62E-1 |
| Laguna and Encinal | -5.0 | 10.0 | 9.52E-5 | 2.44E-4 | 1.02E-4 | 1.37E+1 | 1.64E+1 | 1.20E-1 |
| Monitor at Dump F | 2.7 | 0.0 | 2.25E-3 | 2.27E-3 | 2.25E-3 | 8.06E+1 | 1.40E+2 | 3.11E-1 |
| Monitor at Well 4 | -0.7 | 2.3 | 5.79E-4 | 6.24E-4 | 5.81E-4 | 6.09E+1 | 8.68E+1 | 3.18E-1 |
| Monitor at West Side | -2.0 | 0.7 | 1.52E-3 | 1.53E-3 | 1.52E-3 | 1.04E+2 | - | 2.04E-1 |
| Monitor at Mine Vent | -3.3 | -2.2 | 9.47E-4 | 9.99E-4 | 9.50E-4 | 2.90E+1 | 3.58E+1 | 1.70E-1 |
| Moquino | -1.5 | 5.0 | 3.10E-4 | 4.41E-4 | 3.16E-4 | 4.18E+1 | 4.83E+1 | 3.09E-1 |
| Paguate | 3.0 | 1.0 | 9.67E-4 | 9.88E-4 | 9.68E-4 | 4.49E+1 | 6.45E+1 | 1.93E-1 |
| Seboyeta | 0.0 | 10.0 | 1.25E-4 | 2.28E-4 | 1.30E-4 | 1.30E+1 | 1.72E+1 | 1.07E-1 |
| Range north | 0.0 | 5.0 | 4.07E-4 | 5.27E-4 | 4.13E-4 | 5.08E+1 | 5.56E+1 | 3.52E-1 |
| Range east | -15.0 | 0.0 | 8.40E-6 | 2.28E-5 | 9.03E-6 | 9.30E-1 | 1.52 | 8.26E-3 |
| Range south | 0.0 | -10.0 | 5.58E-4 | 6.47E-4 | 5.62E-4 | 1.01E+1 | 1.29E+1 | 8.41E-2 |
| Range west | -5.0 | 0.0 | 8.01E-5 | 1.00E-4 | 8.09E-5 | 6.83 | 1.06E+1 | 4.67E-2 |

†[1] Concentrations were calculated with the UDAD code for the 99th year following decommissioning. (Radon was calculated using both the UDAD and ISC codes.) Natural background is not included.

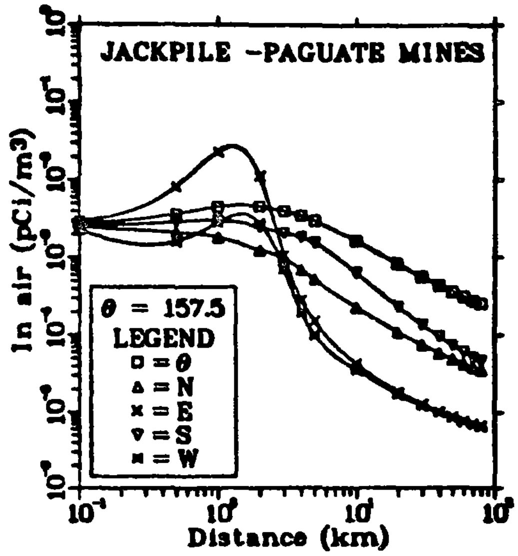
†[2] The "x" axis represents east-west, with a negative sign indicating west; the "y" axis represents north-south, with a negative sign indicating south. The origin of this coordinate system (x=0, y=0) is the confluence of two rivers, Rio Paguate and Rio Moquino, at the approximate center of the mine site (see Fig. 3.4).

†[3] The concentrations of the radionuclides U-234, Th-230, and Ra-226 each would be equal to the concentration of U-238.

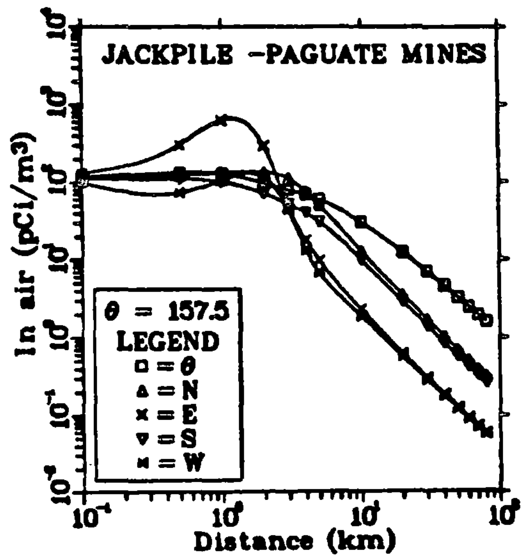
†[4] mWL = 0.001WL




a. U-238




b. Pb-210




c. Po-210

Figure 3.6. Calculated Concentrations of Particulates in the Air at Various Distances from the Mine Complex under Alternative A Conditions. [The concentrations for U-234, Th-230, and Ra-226 each would be the same as for U-238 (Fig. 3.6a). The direction Θ (157.5°) in the graphs is the south-southeast, the direction of maximum transport.]

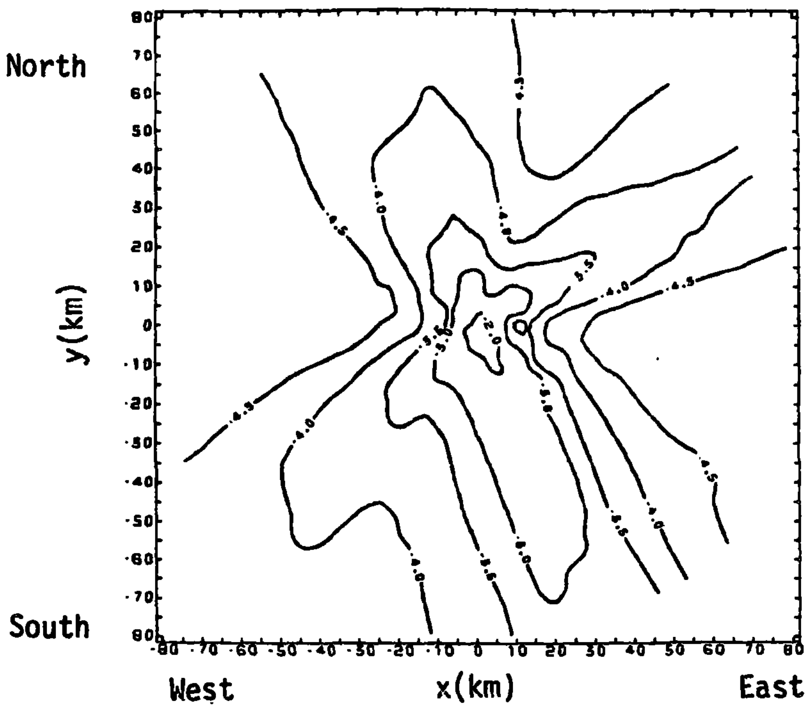



Figure 3.7. Concentration Isopleths for Airborne Ra-226 within 80 km of the Mines. (Numbers equal log [(pCi Ra-226/m$^3$)/maximum permissible concentration of Ra-226 (pCi/m$^3$)].)

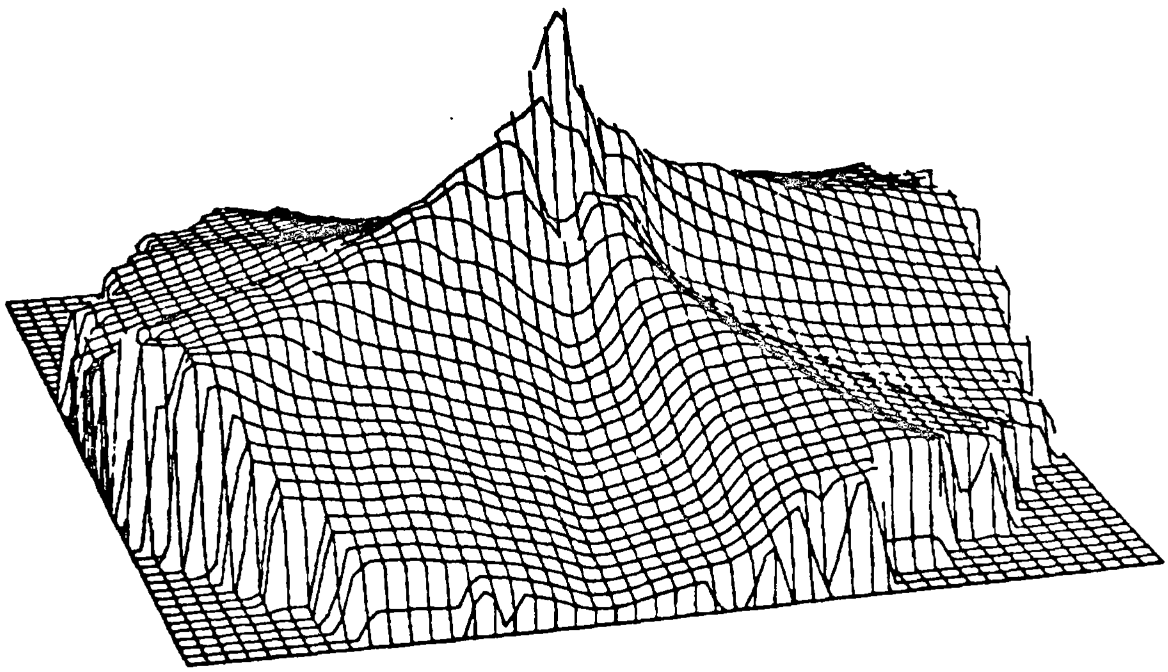


Figure 3.8. Three-Dimensional Depiction of the Ra-226 Concentrations shown in Figure 3.7.

### 3.2.4.2 Radon and Working Level

Alternative A

Based on the UDAD code, the concentration of radon at the Jackpile housing is estimated to be 110 pCi/$m^3$ (Table 3.4). The highest concentration of radon in air among the offsite towns listed in the table is 44.9 pCi/$m^3$ at Paguate. The concentrations of radon in air are shown in Figure 3.9 as a function of distance from the confluence of Rio Paguate and Rio Moquino for five directions--north, south, east, west, and south-southeast (the direction of maximum transport as based on the concentration of radon 20 km from the mines).

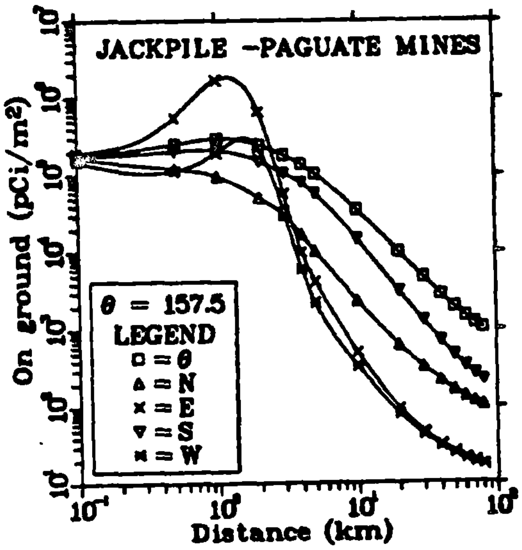



Figure 3.9. Concentrations of Rn-222 in Air at Various Distances from the Mines. (Calculated Using UDAD Code.)

Radon concentration was also calculated using the ISC code (EPA 1979) for the same meteorological conditions and source emissions (Table 3.4). The data indicate that the ISC code calculations are 20% higher than those for the UDAD code.* The working level (WL), a measure of potential exposure to alpha radiation from the short-lived decay products of radon (Po-218 and Po-214),** also is shown in Table 3.4.

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*The relationship between the two sets of concentrations is given by: UDAD = 0.0397 + 0.8301 (ISC) + 0.0014 (ISC)$^2$. The parameters for this polynomial were calculated using a least-squares technique.

**One working level (WL) is defined as any combination of short-lived radon decay product concentrations in one liter of air that will product 1.3 × $10^5$ MeV of alpha energy in their complete decay to Pb-210.

Alternatives B-D

Surfaces of radioactive materials would be covered with 30 cm (1 ft) of soil for Alternative B, and with 180 cm (5 ft) of soil over the mineralized materials (protore, waste piles, and pits) for Alternatives C1-D. The airborne concentrations of radon and radon decay products (working level) calculated from the release rates given in Section 3.2.3 are listed in Table 3.5 for selected locations. The concentrations and working levels under Alternative B and Alternatives C1-D would be 59% and 8%, respectively, of the values calculated for Alternative A. The 8% value is numerically equivalent to a radon flux from the covered surface releasing about two times natural background in the region. Furthermore, the concentrations are small fractions of the background concentration of about 500 pCi Rn-222/$m^3$ (Table 2.7) and the background working level of 3.6 mWL (Sec. 2.5.2.3).

Table 3.5. Total Airborne Concentration of Radon and Working Level Calculated for Alternatives B-D†[1]

| Identification Identification | Location†[2] X(km) | y(km) | Alternative B Concentration†[3] (pCi/$m^3$) | Alternative B Working Level (mWL)†[4] | Alternative C-D Concention†[3] (pCi/$m^3$) | Alternative C-D Working Level (mWL)†[4] |
|---|---|---|---|---|---|---|
| Bibo | -2.0 | 3.0 | 19 | 0.2 | 7.4 | 0.047 |
| Casa Blanca | -10.0 | -10.0 | 2.5 | 0.023 | 1.0 | 0.009 |
| Jackpile-Housing | 0.0 | -0.2 | 6.5 | 0.21 | 25 | 0.081 |
| Laguna and Encinal | -5.0 | 10.0 | 8.1 | 0.071 | 3.7 | 0.028 |
| Monitor at Dump F | 2.7 | 0.0 | 48 | 0.18 | 18.7 | 0.070 |
| Monitor at Well 4 | -0.7 | 2.3 | 36 | 0.19 | 14.0 | 0.074 |
| Monitor at West Side | -2.0 | 0.7 | 61 | 0.12 | 23.8 | 0.047 |
| Monitor at Mine Vent | -3.3 | -2.2 | 17 | 0.10 | 6.6 | 0.039 |
| Moquino | -1.5 | 5.0 | 28 | 0.18 | 10.9 | 0.070 |
| Paguate | 3.0 | 1.0 | 26 | 0.11 | 10.1 | 0.043 |
| Seboyeta | 0.0 | 10.0 | 7.7 | 0.063 | 3.0 | 0.025 |

†[1] Concentrations were calculated with the UDAD code for the 99th year following decommissioning. Natural background is not included.

†[2] The "x" axis represents east-west, with a negative sign indicating west; the "y" axis represents north-south, with a negative sign indicating south. The origin of this coordinate system (x=0, y=0) is the confluence of two rivers, Rio Paguate and Rio Moquino, at the approximate center of the mine complex.

†[3] All concentrations are pCi Rn-222/$m^3$.

†[4] mWL = 0.001 working level (WL).

### 3.2.5 Surface Activity from Ground Deposition of Particulates

The estimated total activity of U-238 on the ground after 99 years of deposition of particulates from the mine complex is shown in Table 3.6 for 15 locations on and around the site under Alternative A conditions.* Since it was assumed for this report that the radionuclides in the Jackpile ore are in secular radioactive equilibrium, the total activity of each radionuclide deposited, except for Po-210 and Pb-210, would equal that of U-238. The activities of Po-210 and Pb-210 would be larger because of the contribution from the radioactive decay of radon.

The activities of the surface-deposited radionuclides are shown in Figure 3.10 as a function of distance from the confluence of Rio Paguate and Rio Moquino. The highest activity among the towns listed in Table 3.6 is the 44,700 pCi U-238/$m^2$ at Paguate. For the same 99-year period, the deposition at the Jackpile housing area would be 176,000 pCi U-238/$m^2$. The measured specific activity of U-238 at the Jackpile housing now is 3 pCi/g (Table 3.1). Conversion from surface activity (in pCi/$m^2$) to concentration (in pCi/g) is not readily feasible because of the variable depth of intermixing of the deposited materials in the upper soil, both by natural forces and mechanical actions. In absence of such mixing, the concentrations could be estimated from the density of uranium oxide (8.3 g/$cm^3$) to be about 2 pCi U-238/g of $U_3O_8$. However, because of intermixing with the dust particles, the concentration would be less than 2 pCi U-238/g of soil. This calculated specific activity does not include the natural background concentration of uranium in soil.

## 3.3 HYDROSPHERIC PATHWAYS

### 3.3.1 Introduction

The principal hydrologic pathways of potential radiation exposure in the vicinity of the Jackpile-Paguate mines are direct ingestion of contaminated water and, indirectly, ingestion of meat from livestock that drink contaminated water. The other hydrologic routes shown in Figure 3.1 are not considered as potential pathways of exposure in this region of New Mexico.

A potential exists for contamination of both groundwater and surface water with radionuclides in the materials on the mine site. At present the source of potable water in the area within 20 km (12 mi) of the mine is groundwater. However, surface waters from the Rio Moquino and Rio Paguate (which pass through the mine) are impounded in the Paguate Reservoir about 6 km (4 mi) south of the mine site. Water in this reservoir is drunk by livestock.

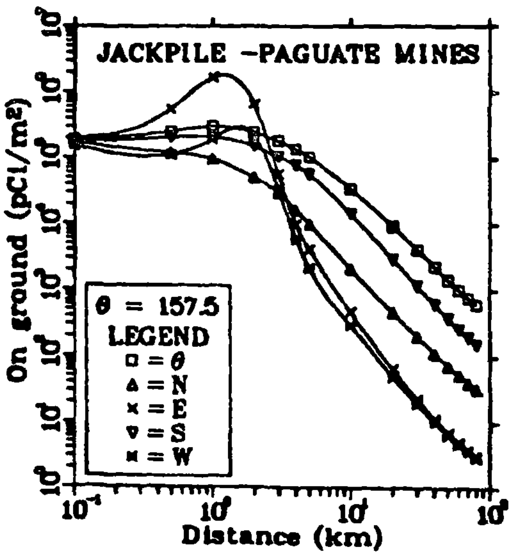
### 3.3.2 Groundwater

Because of the relatively slow rate of migration of solutes in groundwater in most of the southwestern region of the United States, existing concentrations of radionuclides in groundwater in the towns adjacent to the Jackpile-Paguate mines could provide an estimate of the equilibrium concentrations of the radionuclides--an equilibrium between the solute and the radionuclides in the rock matrix established during the periods before mining. These naturally

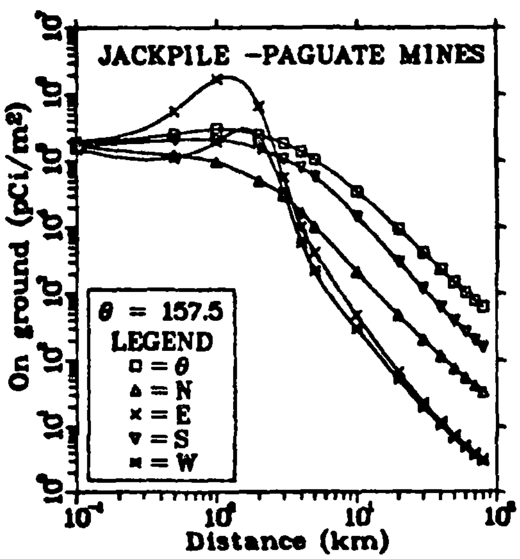
*Particulate emissions would be eliminated under Alternatives B-D.

Table 3.6. Total Activity of U-238 on the Ground after 99 Years of Deposition of Airborne Particulates from Jackpile-Paguate Mines

| Location | Surface Activity ($pCi\ U\text{-}238/m^2$) |
|---|---|
| Bibo | 10,100 |
| Casa Blanca | 2,120 |
| Jackpile-Housing | 176,000 |
| Laguna and Encinal | 1,570 |
| Monitor at Dump F | 131,000 |
| Monitor at Well 4 | 23,100 |
| Monitor at West Side | 129,000 |
| Monitor at Mine Vent | 43,400 |
| Moquino | 7,830 |
| Paguate | 44,700 |
| Seboyeta | 2,130 |
| Range North | 10,200 |
| Range South | 14,800 |
| Range East | 105 |
| Range West | 2,180 |




a. U-238




b. Pb-210

Figure 3.10. Calculated Concentrations of U-238 and Pb-210 on the Ground under Alternative A Conditions. (U-234, Th-230, and Ra-226 concentrations each would be the same as for U-238, and the concentration Po-210 concentration would be the same as for Pb-210.)

occurring concentrations are from dissolution of the radionuclides from the host rock into the water and resorption and removal of the radionuclides by rocks. It is assumed that the climatic and hydrologic patterns existing today have been relatively stable throughout at least most of the past several thousand years. It thus can be surmised that the existing concentrations are in a large part a reflection of the past interactions between the water and the mineralized Jackpile host rock.

In the immediate area of the mines, the mining operations have probably altered the equilibrium ratio of the solute between the host rock and water because of the alteration of the water-flow patterns and physical changes in the host rock. A large volume of groundwater has been removed during the mining process by (1) pumping from underground mines, (2) evaporation from exposed groundwater-bearing strata, and (3) use of water to spray mine roads for control of dust. However, because of the low rate of water flow and the slow rate of migration of radionuclides, the influence of mining on groundwater may not be observed off the site for a long period of time.

The concentration of radionuclides in the groundwater is dependent on groundwater level, amount of mineralized rocks, and mobility of the radionuclides. With the cessation of mining, groundwater recovery on the mine site would eventually increase the groundwater level to near that existing before mining. The removal of the mineralized rocks has reduced the amount of mineralized source material available for migration. The limited available data suggest that oxidation of the residual mineralized rocks still remaining on the mine site, and reduction of the aggregate sizes, has enhanced mobility of the radionuclides. These factors could produce a potential source of radionuclides for migration. Because of this possibility, an upper limit of concentration of radionuclides in groundwater was calculated.

Groundwater flows from recharge areas on the slopes of Mount Taylor toward the valleys below, from impounded water behind the blocked arroyos locally at the mine site, and possibly from direct infiltration of rainfall. The nearest town, Paguate, is west-northwest of the site. The concentration of Ra-226 in groundwater at Paguate is less than 10% of the maximum permissible concentration limit (5 pCi/L) established by the U.S. Environmental Protection Agency, as indicated in Section 2.3. The general direction of groundwater flow (Fig. 2.15) indicates that contamination of the potable water at Paguate from mine sources would not be expected under present water-use conditions. However, despite this expectation, wells between the town and the mine site should be monitored for radionuclides after reclamation.

The nearest use of groundwater for potable supplies south of the mine site is at the town of Laguna, about 10 km (6 mi) south of the southern mine boundary. It was shown in Section 2.3 that the concentration of Ra-226 in the groundwater supplies at Laguna are less than 6% of the U.S. Environmental Protection Agency's maximum permissible concentration limit. Potential impacts of mine sources on the quality of groundwater at Laguna are discussed below.

### 3.3.2.1 Alternative A

Radionuclide concentrations in groundwater between the southern boundary of the mine complex and the town of Laguna were calculated as a function of time and distance for the most mobile (Ra-226) and least mobile (Th-230) radionuclides. Because the structure and characteristics of soils between the mines and the town are not documented, the analysis was limited to estimation of the upper and the lower limits of concentrations. The model and assumptions used for the analysis and the input data are described in Appendix C.2. The potential recharge of groundwater by surface water impounded in Paguate Reservoir and any resulting effects on the quality of the groundwater supply at the town of Laguna were not investigated.

In these analyses, the subsurface medium was assumed to be homogeneous, isotropic, and unbounded in the horizontal plane in the direction of groundwater flow, but vertically bounded by an impervious base. In the first analysis (upper-limit condition), interactions between the dissolved radionuclides and the soil medium were not considered (resorption was assumed to be negligible). The worst condition of solute transport was predicted. In the second analysis (lower-limit condition), interactions between the radionuclides and the soil medium were taken into account. In all cases, the concentrations were calculated as a function of time up to 1,000,000 years and within an aquifer assumed to be confined. Since detailed data on regional groundwater flow are not available, for conservatism the direction of flow was assumed to be directly from the mines toward Laguna. Radiation decay of the radionuclides during migration from the mine site was accounted for in the calculations.

Figure 3.11 is an isoplot (a map showing lines of equal concentrations) of normalized* Ra-226 concentrations at 5000 years following reclamation, constructed under the assumption that there is no resorption. In the coordinate system used, "x" is distance along the direction of groundwater flow and "y" is distance transverse to the direction of flow. The flow was confined to a region only 1500 m wide and parallel to the y-axis. The concentrations were normalized to the concentration of Ra-226 in groundwater at the southern boundary of the mines (distance x = 0). The average measured concentration of Ra-226 in the monitoring wells at the perimeters of the mine is less than 5 pCi Ra-226/L (Table C.1 Appendix C). Calculated on the basis of a concentration of 5 pCi Ra-226/L at the boundary (x = 0), the concentrations at distances of 3 km, 8 km, 9.5 km, and 10 km from the mine boundary to the front of the radium-concentration plume (y = 0) estimated from the normalized concentrations (Fig. 3.11) would be less than 2.5, 0.5, 0.05, 0.00005 pCi/L, respectively. The normalized radium concentrations calculated for the 10,000th year are given in Figure 3.12. At that time, the upper limit concentration of Ra-226 in groundwater at Laguna (x = 10 km) would be 0.05 pCi/L. In these computations, the concentrations have decreased for distances away from the mine boundary due to radioactive decay of the radionuclides during migration.

Under more realistic conditions, that is, assuming that radionuclide concentrations in water flowing from the mine are not at equilibrium with concentrations in down-gradient materials, part of the Ra-226 in solution would then be resorbed during its passage through the ground between the mine and the town of Laguna. Normalized Ra-226 isoplot concentrations calculated for such

*(Concentration at distance x)/(Concentration at distance 0).

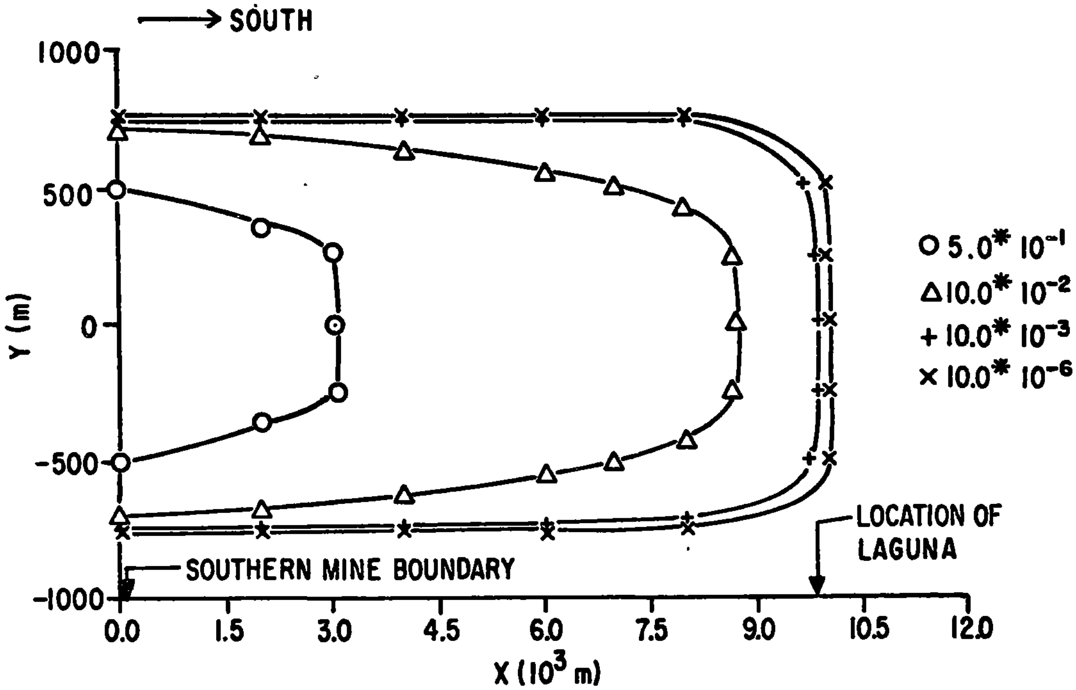



Figure 3.11. Normalized Concentration (pCi/L) of Ra-226 at 5000 Years after Reclamation. (Retardation factor = 1; y-axis is west-east, and x-axis is directed toward the south.)

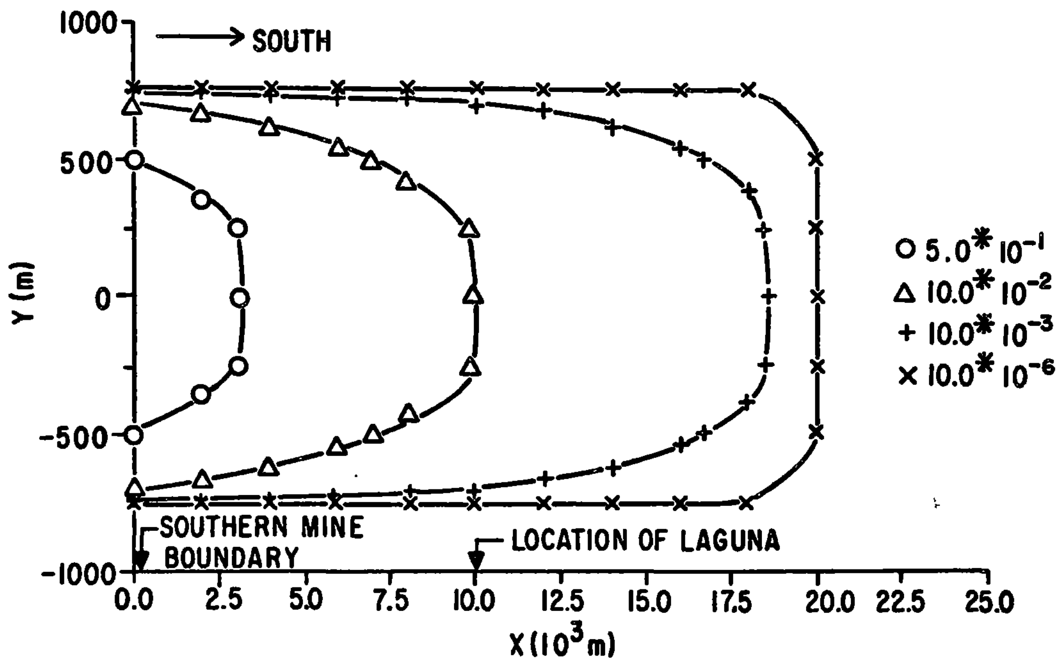



Figure 3.12. Normalized Concentration (pCi/L) of Ra-226 at 10,000 Years after Reclamation. (Retardation factor = 1.)

conditions at 1,000,000 years after reclamation are given in Figure 3.13. At that time, the subsurface radium front would have advanced only 2 km, with a concentration $1 \times 10^{-5}$ of that at the site boundary (5 pCi Ra-226/L). The concentration of thorium, a less mobile element in groundwater, would be much less than that of radium.

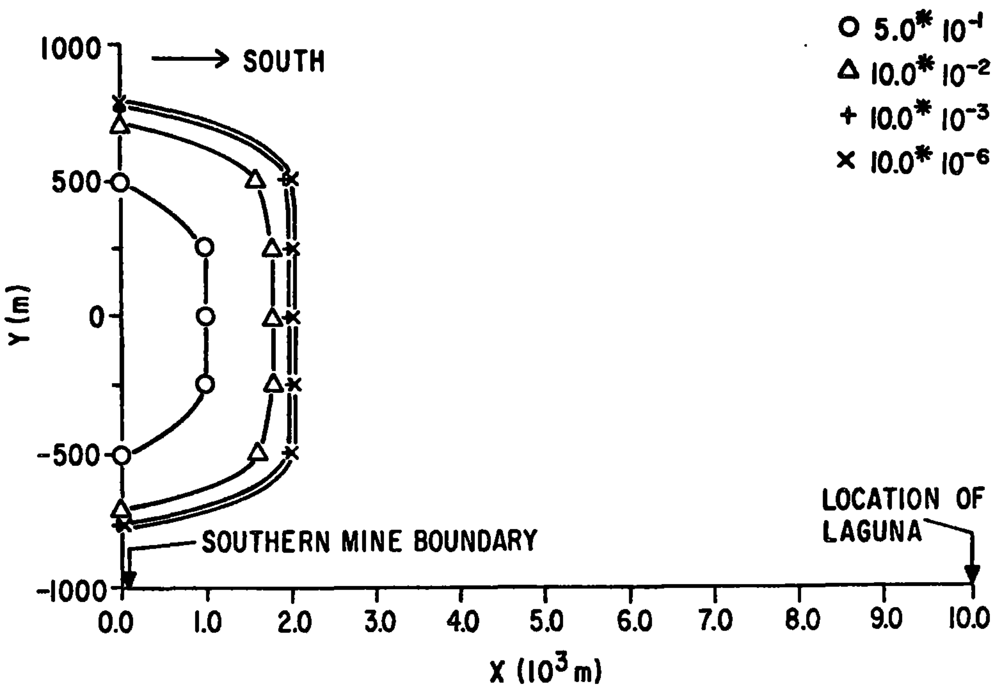



Figure 3.13. Normalized Concentration (pCi/L) of Ra-226 at 1,000,000 Years after Reclamation. (Retardation factor ≠ 1.)

Within the limits of these analyses, the concentrations of migrating radioactivity from the mine site are shown not to exceed the MPC of 5 pCi/L in a public water supply as proposed by the U.S. EPA. Because of the very slow rate of migration of radionuclides in the groundwater and because of resorption of radionuclides during passage through the ground, the establishment of a monitoring system at 10 km from the site boundary would not be expected to provide data on migration of radioactivity resulting from mine operations. However, under special geological conditions where the groundwater flow is enhanced, a more rapid mixing and migration of radionuclides could be possible. Data supporting these possible groundwater pathways for the Jackpile-Paguate mine area are not available.

### 3.3.2.2 Alternatives B-D

Surface soil and vegetative covers that would be placed over the waste piles under Alternatives B through D would control erosion of radioactive waste by surface runoff and subsequent transport into streams and would also eliminate the transport of the radioactive material by fugitive dusting. The cover within the mine pits, however, would reduce loss of groundwater and would result in a higher equilibrium groundwater level either because of elimination or reduction of evaporation. The increase in groundwater level, in turn, could result in increased contact of water with the radioactive material in the mine pits, possibly causing an increased concentration of radioactivity in water discharged into streams within the mine site.

In humid regions, the addition of soil cover over the wastes probably would retard, not reduce or eliminate, infiltration and percolation of rainwater through the soil surface cover and through the waste materials. In the arid Southwest, where evaporation far exceeds precipitation, the rainwater probably would evaporate before it penetrated the waste and percolated into the groundwater. Analyses of surface and groundwater flow patterns to predict possible contamination of groundwater (and thus provide an indication of the need for corrective actions) are reported in Section 5 and Appendix C.

### 3.3.3 Surface Water

At present surface waters are not used for human drinking supplies in the Paguate-Laguna area, so the pathway of direct human consumption of contaminated surface waters is not considered a major exposure route. However, part of the surface water from the Rio Paguate and Rio Moquino (which pass through the mine site) collects in the Paguate Reservoir downstream of the site (Fig. 3.14). Water in the reservoir and in the streams is drunk by livestock. Therefore, the potential exposure pathway of human consumption of meat from livestock that drink contaminated water must be considered.

The Paguate reservoir was constructed by 1940, 13 years before mining began at the Jackpile-Paguate complex. Figures 3.15 and 3.16 are photographs showing two views of the reservoir. The average concentrations of uranium and radium in water samples collected from the reservoir in October 1980 were 0.11 mg total uranium/L and 0.91 pCi Ra-226/L (Eberline Co. 1981). Analyses of water samples collected February 1979 through March 1982 indicated that the average concentrations of total uranium and radium were 0.24 mg/L and 1.03 pCi/L, respectively (Table C.1, Appendix C). These concentrations are below the U.S. Environmental Protection Agency's drinking water standards of 5 mg total uranium/L and 5 pCi Ra-226/L. The radionuclides in the reservoir are partially from natural sources (such as seepage into Rio Paguate and Rio Moquino of groundwater passing through Jackpile sandstone) and partially from sources related to mining operations (such as surface runoff across exposed waste and ore and into the streams). Surface runoff is the major source of contribution of radionuclides from the mine site to surface waters.

Because of the lack of data on surface-water quality under natural conditions prior to mining, the contributions of uranium and radium from natural dissolution of minerals cannot be separated from those contributions attributable to mining. However; the total loadings of uranium and radium contributed by the Jackpile-Paguate mines through both surface runoff and groundwater discharge to streams can be estimated from measured flow rates and concentrations of the radionuclides at sampling stations on Rio Paguate (upstream), Rio Moquino (upstream), and Ford Crossing over the Rio Paguate (downstream) (Figure 2.8).

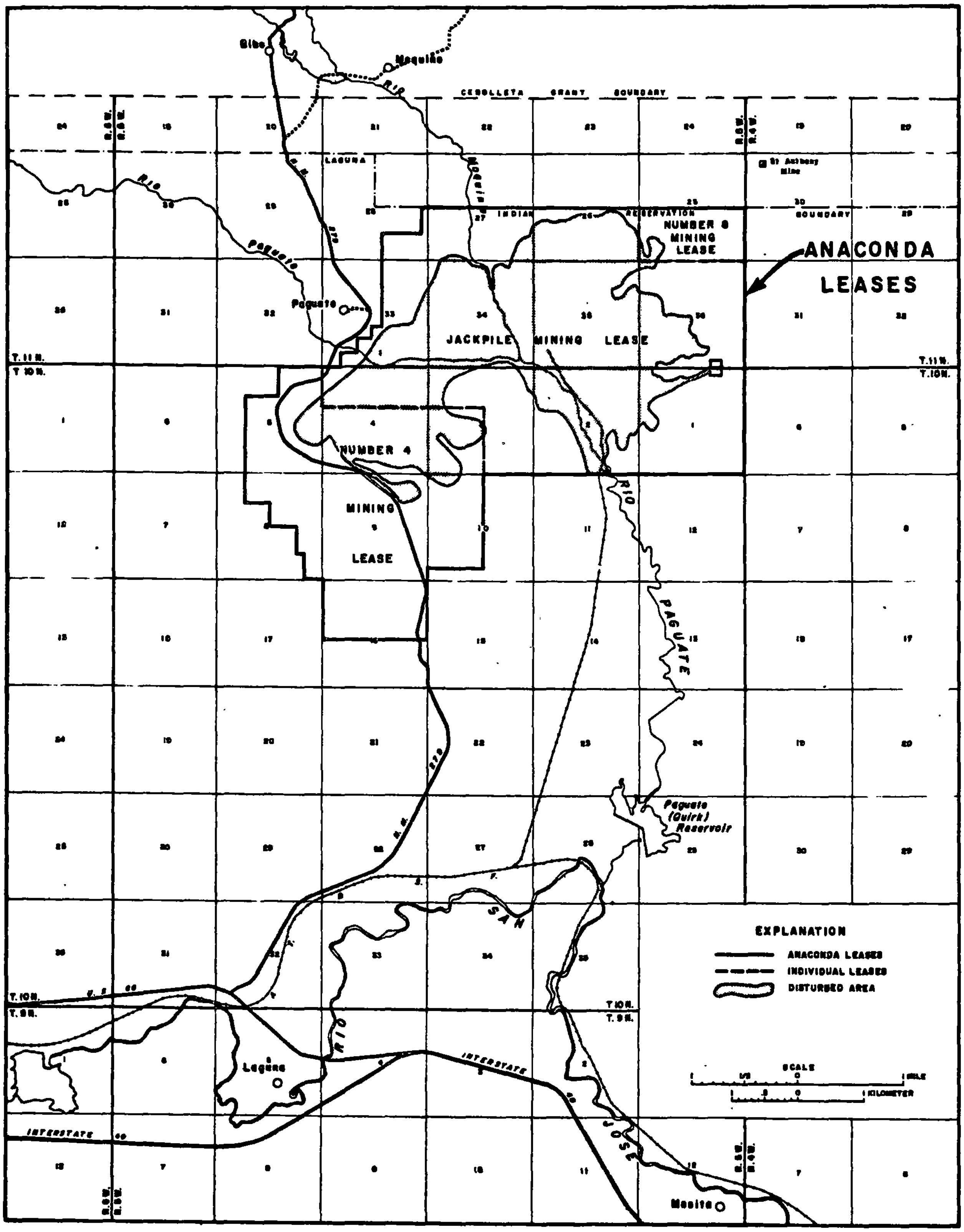



Figure 3.14. Map Showing Location of Paguate Reservoir in Relation to Jackpile-Paguate Mine Complex and the Town of Laguna (in lower left-hand portion of map).

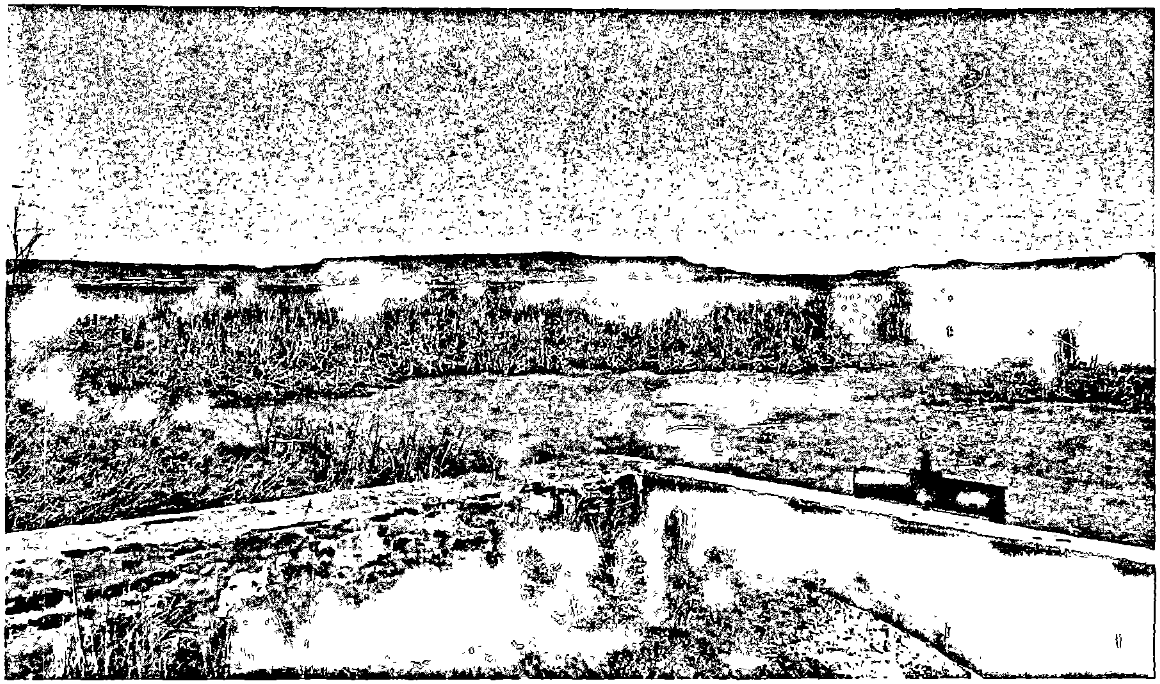


Figure 3.15. Northward View of Paguate Reservoir over the Overflow Dam.

Figure 3.16. Southeastward View of Paguate Reservoir over the Overflow Dam.

Values for mean monthly discharges of Rio Paguate as measured downstream of the Jackpile-Paguate mines near Laguna (Ford Crossing) over the period 1977-1980 were adopted for this analysis (Zehner 1982). The average mean annual flow for that period, computed to be about 33.7 L/s (1.19 cfs), was adjusted by the drainage area-discharge ratio for two upstream locations--one on Rio Paguate upstream of the mines and one on Rio Moquino upstream of the mines. Average concentrations of radium and total uranium, as given in Table 3.7, were computed from measured concentrations in monthly samples collected by the Anaconda Co. during the period February 1979 through March 1982. The total loadings of uranium and radium were calculated for the same three locations (Table 3.7). These calculations were based on the assumption that on the average, the sampled concentrations were representative of the period when the streamflow rates were measured. These analyses indicate that the total annual loadings of the streams to the reservoir are 3964 µCi of Ra-226 and 254 kg (559 lb) of natural uranium. These loadings can be separated into 299 µCi Ra-226 per year and 7.3 kg (16.1 lb) natural uranium per year from areas upstream of the mine complex, and 3665 µCi Ra-226 and 246.7 kg (543 lb) natural uranium per year from within the mine complex.

A radiological assessment of the Paguate Reservoir conducted for the Anaconda Co. (Eberline 1981) included radiological analysis of a number of core samples of reservoir sediments and of ground from the area around the reservoir. For this document, results from Anaconda's analyses were evaluated for selected core samples to seek an indication of the influence of mining operations on the amount of radioactivity in sediments of the Paguate Reservoir. The measured concentrations of bismuth-214 (Bi-214)* in core samples from four locations representing background conditions near the reservoir were compared with concentrations in four core samples from reservoir sediments. The results of radiological analysis of the cores from background locations are shown in Figure 3.17, and the results for the reservoir sediment cores are shown in Figure 3.18.

Comparison of the Bi-214 concentrations from the samples taken at the four background locations indicate significant variations at the same depth among the four samples; the results from the reservoir sediment cores also show significant variations. It is not apparent from these data to what extent mining has contributed to radionuclide concentrations in the reservoir. The top (6 ft) of reservoir sediments have been deposited during the mining period. As shown in Figure 3.18, there is some indication of higher average Bi-214 concentrations in this portion of the sediments than in both the lower portions of the sediment cores and in the upper portions of the cores from the areas selected as background.

Under decommissioning Alternative A (No-Action Case), surface erosion of the waste piles into streams could significantly influence downstream concentrations of the radionuclides and sediments. Under Alternatives B through D, however, exposed radioactive material on the surfaces of the mine site would be covered, and the radioactivity of any sediments from the site would be similar to that from a comparable area of natural soil.

As indicated in Figure 3.19, the alluvium deposits upstream of the reservoir are naturally eroded. This seems to suggest that naturally and in the absence

*Under conditions of secular radioactive equilibrium, concentrations of Bi-214 can be equated to those of Ra-226.

Table 3.7. Quantity (loading) and Concentrations of Ra-226 and Natural Uranium Discharged from the Rio Moquino and Rio Paguate into Paguate Reservoir

| | | | Concentrations | | Annual Loading | |
|---|---|---|---|---|---|---|
| Location†[1] | Drainage Area†[2] ($km^2$) | Mean Annual Flow (L/s) | Ra-226 (pCi/L) | Natural Uranium (mg/L) | Ra-226 (μCi/yr) | Natural Uranium (kg/yr) |
| Rio Paguate (upstream) | 80 | 9.7 | 0.35 | 0.006 | 107 | 1.8 |
| Rio Moquino (upstream) | 178 | 21.7 | 0.28 | 0.008 | 192 | 5.5 |
| Total loading from both streams (upstream) | | | | | 299 | 7.3 |
| Ford crossing (downstream) | 277 | 33.7 | 3.73 | 0.239 | 3964 | 254 |
| Total loading from mine site | | | | | 3665 | 246.7 |

†[1] See Figure 2.8 for location of gage stations.

†[2] See Zehner (1983).

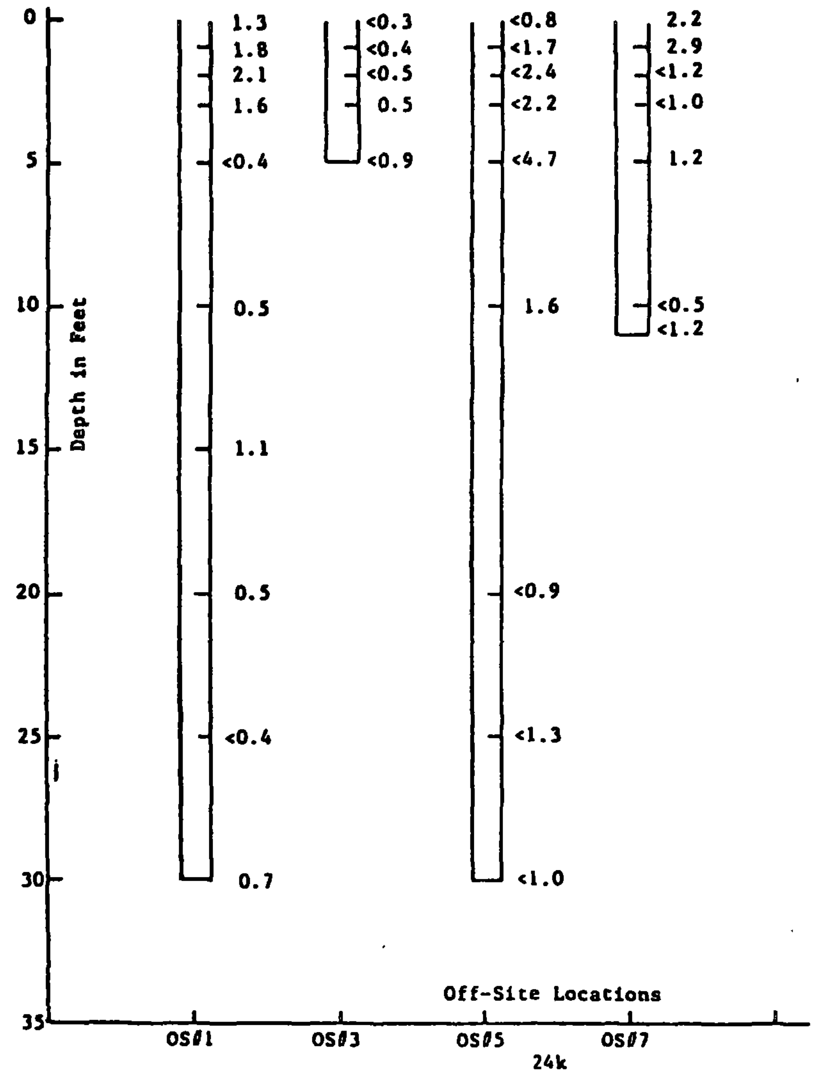



Figure 3.17. Bismuth-214 Concentrations in Core Samples from Background Locations near Paguate Reservoir. (From Eberline Co. 1981, Boring Log #11.)

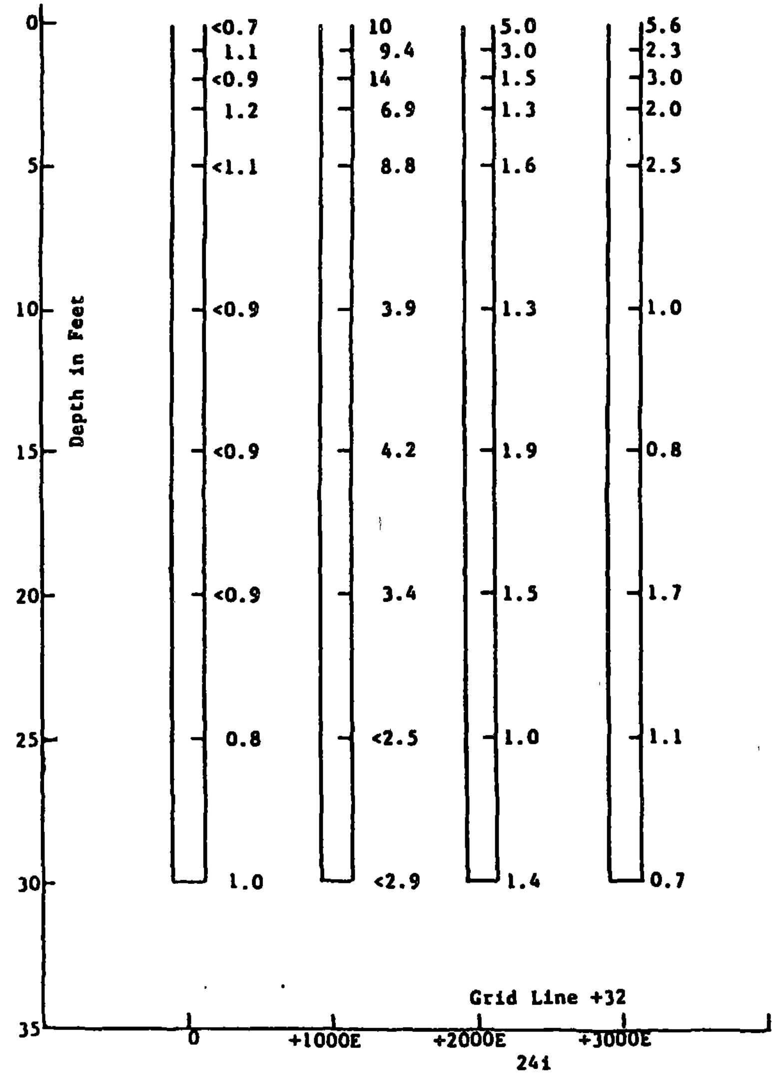



Figure 3.18. Bismuth-214 Concentrations in Core Samples of Sediments from Paguate Reservoir. (From Eberline Co. 1981, Boring Log #9.)

Figure 3.19. Photo Showing Natural Erosion along the Rio Moquino Upstream from the Bridge between Seboyeta and Sohio Mill North of the Mine Complex.

of mining, erosion would have carried mineralized deposits away from the Jackpile-Paguate area, and steadily increased the quantity and concentration of radionuclides in materials deposited downstream of the site.

## 3.4 RADIATION DOSES FROM EACH PATHWAY OF EXPOSURE

In the previous sections, pathways of exposure were defined and calculations of the concentrations of the radionuclides in air, on soil, and in water were presented. In this section, calculations of the potential radiation doses resulting from human exposure to those radionuclides are summarized.

The principal pathways of exposure were identified as inhalation of airborne radionuclides, ingestion of contaminated food and/or water, and external exposure. In the inhalation and ingestion pathways, the radionuclides are carried to different organs of the body by physiological processes and are absorbed into the blood stream. Some of the radionuclides accumulate in specific organs (for example, radium accumulates in bone).

Some organs show higher sensitivity than others to induction of radiation health effects or transmital of genetic abnormalities (e.g., gonads). The organs that either show higher sensitivity to radiation or accumulate radionuclides are often referred to as tissues at risk. The dose rates, doses, dose commitments, and environmental dose commitments to these tissues at risk were calculated with the UDAD code for the various decommissioning alternatives. For purposes of risk assessment, these calculations were made for ten time intervals up to a period of 95 years after reclamation. Descriptions of the methods used and of models of radionuclide transport within the human body are given in the UDAD manual (Momeni et al. 1979). The results of the dose-rate and dose calculations for the inhalation, ingestion, and direct exposure pathways in vicinity of the Jackpile-Paguate mines are summarized below and presented in detail in Appendix D.

### 3.4.1 Inhalation

Potential doses from inhalation result from exposure to (1) airborne particulates (all the radionuclides in the uranium series except those from short-lived radon daughters), and (2) airborne radon decay products that enter the respiratory system. A fraction of the total activity inhaled is directly exhaled. A fraction of the activity deposited in the respiratory system is subsequently ingested.

The procedure for calculating radiation dose rate and dose from inhalation of particulates and radon is based on the 1966 recommendations of the Task Group on Lung Dynamics, Committee II, for the Internation Commission on Radiological Protection (ICRP 1966). In the model recommended by the ICRP, the respiratory system is divided into three major regions corresponding to the sites of deposition of the radionuclides--the nasopharyngeal (NP), the tracheobronchial (TB), and the pulmonary (P) regions. Partition of the activity into these compartments of the respiratory system is dependent on the size of the inhaled airborne particulates. The size distribution of the airborne particles is not known for the mine site; the values selected for these calculations are given in Appendix D. The fraction of deposited radionuclides that is transported from the lung compartment into the blood stream is dependent on the physiological solubility of the radionuclides. The solubility classifications are based on the recommendations of ICRP (ICRP 1966).

The dose rate (the rate of absorption of radiation energy in a tissue) from the inhalation of an airborne radionuclide is proportional to the cumulative concentration of the radionuclide previously inhaled. Since the concentration is in effect a net result of intake, excretion, and radioactive decay, the concentration in the tissue is not constant; it increases eventually to an equilibrium value with continuous intake of the radionuclide.

The total dose from inhalation of radionuclides is a summation of the individual dose rates received each successive year.

#### 3.4.1.1 Alternative A

Because there would be no reclamation of the site under Alternative A, it would represent the maximum dose conditions of the five alternatives considered.

The average dose rates and corresponding doses to the nasopharyngeal, tracheobronchial, and pulmonary regions of the lung from inhalation of particulates and to bronchial epithelium from inhalation of radon decay products are given in Table 3.8 for selected locations around the site. The dose rates are for 70th year after decommissioning, and the corresponding doses are for the 70th year (the assumed average human life expectancy in the region).

For particulates, dose rate and dose to the nasopharyngeal region are larger than to other regions of the lung because the filtration action in the nasopharyngeal region removes the larger airborne particles as the inhaled air passes through the respiratory system. The largest dose rate (and dose) for someone breathing through their mouth would be to the tracheobronchial region. The dose from inhalation of particulates increases with time and is dependent on the period of exposure.

For inhalation of radon decay products, the total dose rate was calculated on the basis of 14 hours (58%) daily residence inside a structure and 10 hours outside. This differentiation between the time spent inside and that spent outside is intended to account for the higher buildup of radon decay product concentrations in a building than in the open space outside. Since the dose to the other organs of the body from radon is relatively small, only the dose rate to the bronchial epithelium, the most sensitive lung tissue, was calculated. The annual average dose rate is constant because the half-lives of the radon decay products are relatively short, and the concentration of these decay products would not build up in the body. However, even though the dose rate is constant, the total dose increases with time. The total dose received from the radon decay products is dependent, among other factors, on the period of residency at a given location. After reclamation of the mine, the dose rate and dose from radon would be mostly from recent exposures, but those radioactive particulates inhaled prior to reclamation would continue to irradiate body tissue throughout the remainder of an individual's life.

As indicated in Table 3.8, among selected locations off the site, the largest doses from inhalation of airborne radionuclides would be at Paguate, the nearest town. Those doses are $2.04 \times 10^{3}$, $8.67 \times 10^{-1}$, and $3.57 \times 10^{-2}$ mrem, respectively, to nasopharyngeal, tracheobronchial, and pulmonary regions of the respiratory system for inhalation of particulates, and $1.96 \times 10^{3}$ mrem to bronchial epithelium from inhalation of radon. The dose rates and doses to selected tissues of the residents of Paguate from inhalation of airborne radionuclides under Alternative A are shown as a function of time in Figure 3.20.

### 3.4.1.2 Alternatives B-D

Under Alternatives B through D, the residual ores and radioactive wastes on the site would be covered with varying amounts of soil. As a result, release of particulates into the atmosphere from the mine site would be greatly reduced, or eliminated. This, in turn, would reduce the dose rate and dose from particulates to values corresponding to background. (A photograph of a previously reclaimed and vegetated waste pile is shown in Fig. 3.21).

The rate of radon release would be reduced but not eliminated (see Sec. 3.2.3.2). Under Alternative B, the dose rates and doses would be about 59% of those for Alternative A, and under Alternatives C1 through D, they would be 8% of the values under Alternative A.

Table 3.8. Inhalation Dose Rate and Dose At Selected Receptor Locations

| Location†[1] | From Particulates | | | From Radon |
|---|---|---|---|---|
| | Nasopharyngeal | Tracheobronchial | Pulmonary | Bronchial Epithelium |
| | | Dose-Rate (mrem/yr)†[2] | | |
| Bibo | 8.87 | 3.93E-3 | 1.67 | 1.97E+1 |
| Casa Blanca | 3.06 | 1.44E-3 | 6.19E-1 | 2.66 |
| Jackpile-Housing | 8.19E+1 | 3.32E-2 | 1.37E+1 | 6.87E+1 |
| Laguna and Encinal | 2.77 | 1.34E-3 | 5.83E-1 | 8.58 |
| Monitor at Dump F | 6.88E+1 | 2.84E-2 | 1.18E+1 | 5.04E+1 |
| Monitor at Well 4 | 1.74E+1 | 7.56E-3 | 3.20 | 3.81E+1 |
| Monitor at West Side | 4.73E+1 | 1.85E-2 | 7.54 | 6.49E+1 |
| Monitor at Mine Vent | 2.87E+1 | 1.22E-3 | 5.13 | 1.81E+1 |
| Moquino | 9.16 | 4.21E-3 | 1.80 | 2.61E+1 |
| Paguate | 2.93E+1 | 1.25E-2 | 5.23 | 2.80E+1 |
| Seboyeta | 3.65 | 1.75E-3 | 7.56E-1 | 8.10 |
| | | Dose (mrem)†[3] | | |
| Bibo | 6.19E+2 | 2.74E-1 | 1.14E+2 | 1.38E+3 |
| Casa Blanca | 2.14E+2 | 9.99E-2 | 4.22E+1 | 1.86E+2 |
| Jackpile-Housing | 5.71E+3 | 2.31 | 9.34E+2 | 4.81E+3 |
| Laguna and Encinal | 1.94E+2 | 9.35E-2 | 3.97E+1 | 6.01E+2 |
| Monitor at Dump F | 4.80E+3 | 1.98 | 8.06E+2 | 3.53E+3 |
| Monitor at Well 4 | 1.22E+3 | 5.26E-1 | 2.18E+2 | 2.66E+3 |
| Monitor at West Side | 3.30E+3 | 1.29 | 5.14E+2 | 4.54E+3 |
| Monitor at Mine Vent | 2.00E+3 | 8.50E-1 | 3.50E+2 | 1.27E+3 |
| Moquino | 6.40E+2 | 2.93E-1 | 1.23E+2 | 1.83E+3 |
| Paguate | 2.04E+3 | 8.67E-1 | 3.57E+2 | 1.96E+3 |
| Seboyeta | 2.55E+2 | 1.21E-1 | 5.15E+1 | 5.67E+2 |

†[1] Locations designated as "monitors" are sites for continuous monitoring of airborne particulates and radon.

†[2] For 70th year after reclamation.

†[3] Time-integrated dose for 70th year of inhalation.

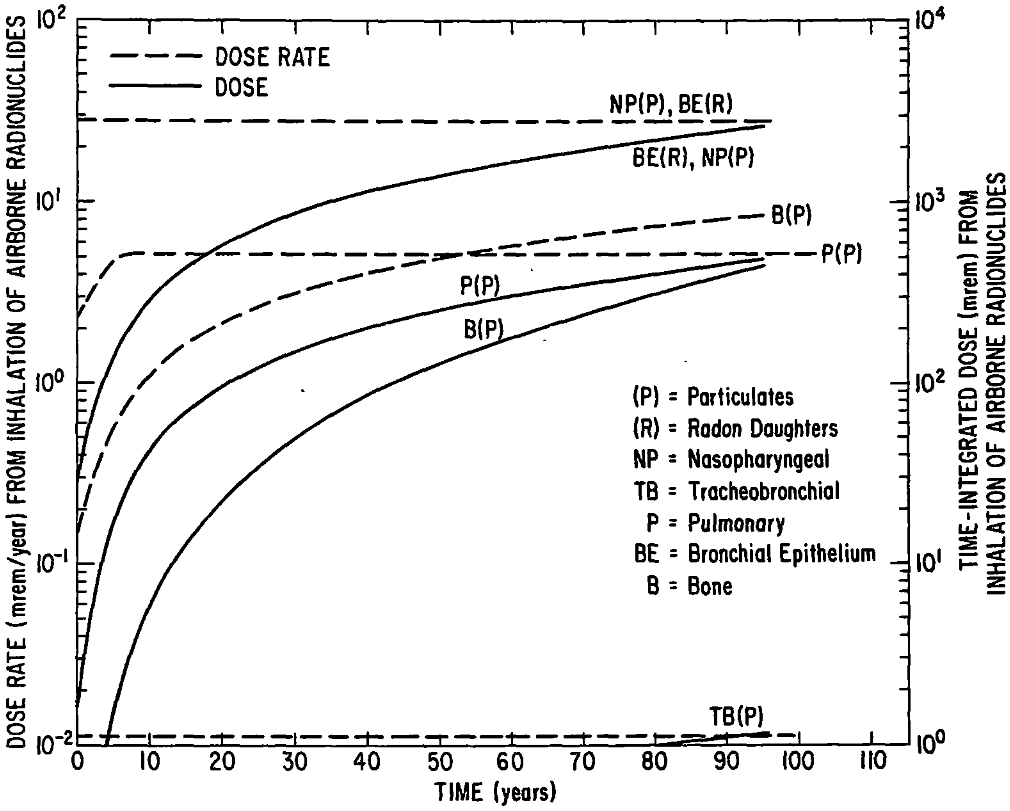



Figure 3.20. Dose Rate and Doses to Residents of Paguate from Inhalation of Airborne Radionuclides under Alternative A.

Figure 3.21. Photograph of a Waste Dump Previously Reclaimed and Revegetated with Native Species.

### 3.4.2 Ingestion

Radiation doses from ingestion normally result from consumption of food and/or water contaminated with radionuclides. However, as was indicted in Section 3.3, it seems unlikely that radionuclides from the Jackpile-Paguate mine complex would become a source of contamination of potable groundwater supplies in the region for the next hundred years. Furthermore, surface water is not used for human consumption in the area at this time. Because of this, the only ingestion pathway considered here is consumption of contaminated food. The land in the region does not support crops; the only agricultural product is meat from livestock raised on the open ranges (see Fig. 3.22). Therefore, this analysis of dose rates and doses from ingestion is restricted to consideration of the consumption of locally grown meat.

Two approaches have been used in this analysis--(1) evaluation of the doses that would result at selected locations if meat from livestock grown near those locations were consumed only in the area where grown, and (2) evaluation of the doses that would result if equal portions of meat raised within 80 km (50 mi) of the mine complex were consumed by all members of the population within the region.

For the first analysis, it was assumed that the amount of meat produced in the an area would not be sufficient to provide for the entire yearly intake of the local residents, and thus locally grown meat would constitute less than 100% of the diet near the location where it was grown. The actual percentage selected varied from location to location, and was the highest for the ranchers in the four ranges around the perimeter of the mine complex.

The second approach--calculation of the average doses that would result if consumption of the meat raised within 80 km (50 mi) of the mine complex were distributed among the entire population of the region--was undertaken to provide an estimate of population dose based on agricultural marketing and distribution patterns.

#### 3.4.2.1 Alternative A

Under Alternative A, no grazing of livestock would be permitted on the mine site. However, the radioactive materials now exposed on the site would not be covered, and offsite transport of radionuclides by natural processes (e.g., wind erosion, surface runoff) would continue. Therefore, livestock would continue to be exposed to and consume radionuclides originating from the unreclaimed mine complex.

The total dose rates and doses to the bone, kidney, liver, and whole body of residents of Paguate under these conditions and for the assumption that locally grown meat is consumed locally are plotted as a function of time in Figure 3.23. The predicted changes in the dose rates are attributable to accumulation of the radionuclides in the tissues and to increases in ground contamination of radionuclides with time. Some tissues, such as bone, retain a larger fraction of the calcium analogs, such as radium. As indicated in the figure, the dose to bone for residents of Paguate from continuous ingestion (over 70 years) of meat raised locally would be 541 mrem. Dose rates and doses for other organs are given in Appendix D.

Figure 3.22. Cattle Graze on Typical Forage Land in the Rio Moquino Valley North of the Mine Complex. (View is southward toward the mine site. The water is impounded rain runoff.)

The average doses for the entire population within 80 km (50 mi) of the mine complex are summarized in Table 3.9. In the 70th year, the average doses received by each individual under these conditions would be $1.48 \times 10^{-3}$ mrem whole body, $1.40 \times 10^{-2}$ mrem bone, $6.24 \times 10^{-3}$ mrem kidney, and $1.84 \times 10^{-3}$ mrem liver. These doses are much less than those calculated under the condition of local products and local consumption of the locally raised meat (Fig. 3.23).

### 3.4.2.2 Alternatives B-D

Under Alternative B, grazing would not be permitted on the mine site; under Alternatives C1 through D, grazing of livestock on the reclaimed mine complex would be allowed, but the sources of airborne particulates would have been covered and thus would not contribute to contamination of the meat of the livestock grazing there. In addition, there would be no further offsite transport of particulates from the mine complex.

Under all the reclamation alternatives (B-D), some offsite contamination of meat would occur after reclamation because of the continued presence of previously deposited radionuclides. However, radiation doses from consumption

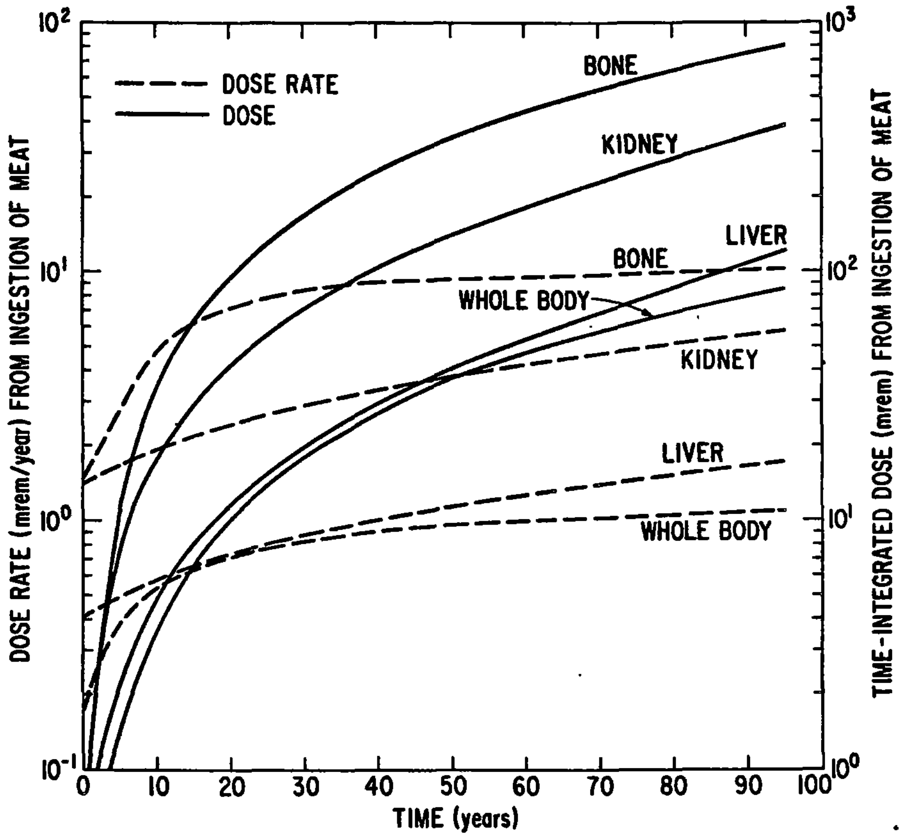



Figure 3.23. Dose Rate and Doses to Residents of Paguate from Ingestion of Meat under Alternative A Conditions.

Table 3.9. Average Time-Integrated Dose to Individuals (standard men) from Ingestion of Locally Raised Meat within 80 km of the Mine Complex

| | Dose (mrem) | | | |
|---|---|---|---|---|
| Time†[1] | Whole Body | Bone | Kidney | Liver |
| 1 | 3.21E-6 | 2.62E-5 | 3.01E-5 | 9.11E-6 |
| 5 | 3.45E-5 | 3.13E-4 | 2.03E-4 | 5.77E-5 |
| 10 | 9.62E-5 | 8.96E-4 | 4.58E-4 | 1.30E-4 |
| 15 | 1.74E-4 | 1.64E-3 | 7.48E-4 | 2.15E-4 |
| 20 | 2.63E-4 | 2.49E-3 | 1.07E-3 | 3.10E-4 |
| 25 | 3.62E-4 | 3.44E-3 | 1.43E-3 | 4.16E-4 |
| 35 | 5.80E-4 | 5.53E-3 | 2.26E-3 | 6.60E-4 |
| 50 | 9.46E-4 | 9.01E-3 | 3.76E-3 | 1.10E-3 |
| 70 | 1.48E-3 | 1.40E-2 | 6.24E-3 | 1.84E-3 |
| 95 | 2.19E-3 | 2.07E-2 | 1.01E-2 | 2.98E-3 |

†[1] Years after decommissioning.

of this meat would not be attributable to reclamation, but instead to activities and conditions existing prior to reclamation. The concentration of such radionuclides would diminish with time by further dilution and dispersion as a result of such natural forces as fugitive dusting and surface runoff of rain water.

### 3.4.3 External Exposure

External exposure consists of exposure to radiation emitted from the airborne and ground-deposited radionuclides on the site and in the surrounding region and to gamma radiation emitted directly from the waste piles and residual ores on the site.

#### 3.4.3.1 Alternative A

Public access to the mine site would be restricted under Alternative A, thus there will be no direct exposure of the population to the gamma radiation emitted from the exposed radioactive materials on the site. However, offsite transport of the radioactive material on the site would continue as a result of natural erosive forces. Residents of the region around the mine complex would receive external exposure from such material deposited on the ground or resuspended in the air off the site. The dose rates and time-integrated doses to the whole body and ovaries of the residents of Paguate from external exposure to ground-deposited and airborne radionuclides are plotted in Figure 3.24. The dose rates from ground-deposited radionuclides would increase with time because more and more material would be transported off the mine complex.* The dose rates from airborne radionuclides would remain relatively constant because of equilibrium between the processes of deposition and resuspension.

The dose rates and doses to other organs of the body and for the residents of other locations in the region are provided in Appendix D.

#### 3.4.3.2 Alternatives B-D

Under the reclamation alternatives (Alternatives B-D), the soil cover placed over wastes and residual ores would attenuate the direct gamma radiation and limit the external radiation exposure on the site to that from the soil cover, a level corresponding to the natural background. However, reclamation would not eliminate the radionuclides previously deposited off the mine site. Thus, these nuclides (either ground-deposited or airborne from resuspension) would continue to be a decreasing source of external exposure. Dose rates and doses from such exposure are not taken into account here because the conditions will be a result of past activities and will be independent of the specific reclamation program undertaken on the site.

*These dose rates do not include any exposure from the radiation directly emitted from the radioactive materials remaining on the mine site.

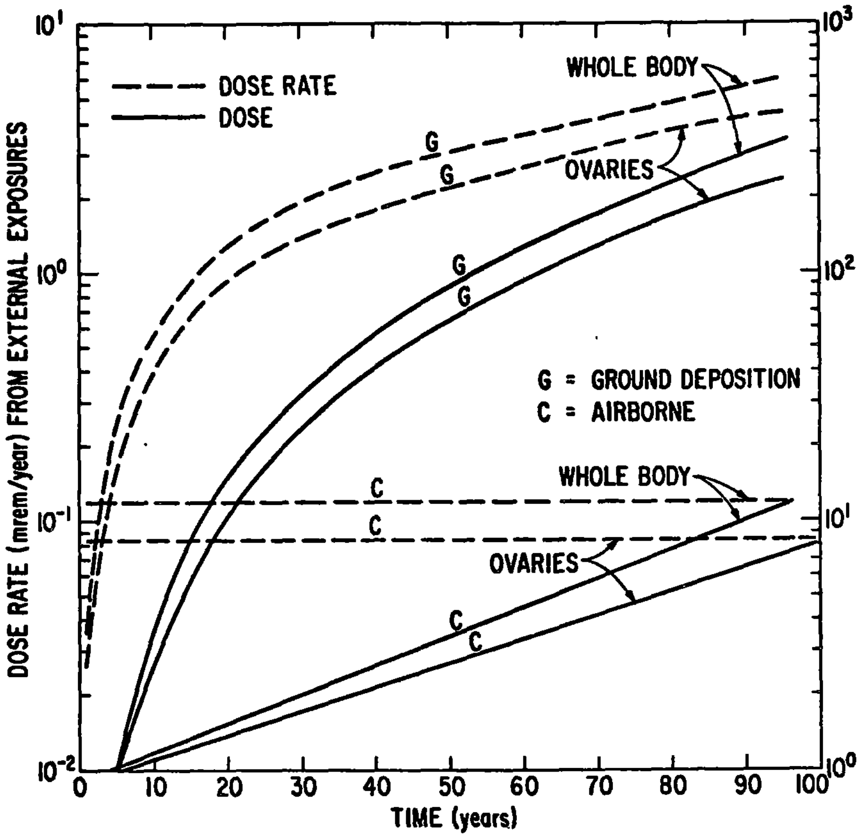



Figure 3.24. Dose Rate and Dose to Residents of Paguate from External Exposure under Alternative A Conditions.

## 3.5 DOSE COMMITMENTS

In this section, individual, population, and environmental dose commitments (organ-rem/yr) for selected locations in the area within 80 km (50 mi) of the Jackpile-Paguate mines are presented for inhalation, ingestion, and direct external exposures attributable to releases of radionuclides from the mine complex. Procedures outlined in the UDAD code manual (Momeni et al. 1979) were used to make the calculations.

### 3.5.1 Alternative A

The individual and population dose commitments listed in Tables 3.10 through 3.13 reflect exposure throughout the life span of an individual or all members of the population under the conditions of Alternative A. The commitments were calculated for a 70-year period.*

*For radiation workers, a population dose commitment of 50 years (70 years minus 20 years, where 20 is the minimum age allowed for radiation workers) has been used. Since the exposure to the general population cannot be limited to any specific age group, all ages are included.

Table 3.10. 70-Year Individual Dose Commitments from Inhalation under Alternative A Conditions for Selected Locations (organ-mrem/yr)

| | Particulates | | | | | Radon | |
|---|---|---|---|---|---|---|---|
| | | | Lung†[1] | | | | |
| Location | Bone | Kidney | NP | P | TB | BE†[1] | WLM†[2] |
| Bibo | 2.10 | 5.85E-1 | 8.91 | 1.67 | 3.94E-3 | 1.97E+1 | 4.35E-3 |
| Casa Blanca | 7.68E-1 | 2.21E-1 | 3.07 | 6.20E-1 | 1.44E-3 | 2.66 | 7.14E-4 |
| Jackpile-Housing | 1.78E+1 | 4.92 | 8.23E+1 | 1.37E+1 | 3.33E-2 | 6.87E+1 | 1.18E-2 |
| Laguna and Encinal | 7.27E-1 | 2.20E-1 | 2.78 | 5.83E-1 | 1.35E-3 | 8.58 | 2.26E-3 |
| Monitor at Dump F | 1.52E+1 | 4.21 | 6.92E+1 | 1.18E+1 | 2.85E-2 | 5.04E+1 | 9.11E-3 |
| Monitor at Well 4 | 4.04 | 1.12 | 1.75E+1 | 3.20 | 7.58E-3 | 3.81E+1 | 7.76E-3 |
| Monitor at West Side | 9.94 | 2.75 | 4.75E+1 | 7.55 | 1.85E-2 | 6.49E+1 | 9.69E-3 |
| Monitor at Mine Vent | 6.53 | 1.81 | 2.88E+1 | 5.14 | 1.22E-2 | 1.81E+1 | 3.89E-3 |
| Moquino | 2.25 | 6.36E-1 | 9.20 | 1.81 | 4.21E-3 | 2.61E+1 | 6.26E-3 |
| Paguate | 6.66 | 1.84 | 2.94E+1 | 5.24 | 1.25E-2 | 2.80E+1 | 5.28E-3 |
| Seboyeta | 9.35E-1 | 2.71E-1 | 3.67 | 7.57E-1 | 1.75E-3 | 8.10 | 2.06E-3 |

†[1] Lung compartments: NP = nasopharyngeal; P = pulmonary; TB = tracheobronchial; BE = bronchial epithelium.

†[2] WLM = Working Level Month; a unit of exposure resulting from exposure to one WL for one working month (170 hours per month). For continuous exposure of the public, an effective working level month is 4.2 working level months (720 hours per month ÷ 170).



Table 3.11. 70-Year Individual Dose Commitments from Ingestion under Alternative A Conditions for Selected Locations (organ-mrem/yr)

| Location | Bone | Kidney | Liver | Whole Body |
|---|---|---|---|---|
| Bibo | 2.33 | 1.51 | 4.50E-1 | 2.51E-1 |
| Casa Blanca | 4.87E-1 | 3.35E-1 | 9.96E-2 | 5.27E-2 |
| Laguna and Encinal | 3.65E-1 | 2.76E-1 | 8.22E-2 | 3.96E-2 |
| Moquino | 1.80 | 1.20E-1 | 3.57E-1 | 1.95E-1 |
| Paguate | 1.04E+1 | 6.68 | 1.99 | 1.12 |
| Seboyeta | 4.88E-1 | 3.46E-1 | 1.03E-1 | 5.29E-2 |
| Range North | 2.33 | 1.54 | 4.59E-1 | 2.52E-1 |
| Range South | 3.39 | 2.22 | 6.60E-1 | 3.66E-1 |
| Range East | 2.43E-2 | 1.97E-2 | 5.86E-3 | 2.65E-3 |
| Range West | 5.02E-1 | 3.31E-1 | 9.82E-2 | 5.42E-2 |

Table 3.12. 70-Year Individual Dose Commitments from External Radiation Exposure under Alternative A Conditions for Selected Locations (organ-mrem/yr)

| Location | Lung | Ovaries | Red Marrow | Testes | Whole Body |
|---|---|---|---|---|---|
| | | Airborne Radionuclides | | | |
| Bibo | 1.42E-1 | 1.10E-1 | 1.59E-1 | 1.30E-1 | 1.51E-1 |
| Casa Blanca | 3.37E-2 | 2.65E-2 | 3.73E-2 | 3.03E-2 | 3.57E-2 |
| Jackpile-Housing | 1.69E-1 | 1.26E-1 | 1.94E-1 | 1.61E-1 | 1.80E-1 |
| Laguna and Encinal | 1.03E-1 | 8.07E-2 | 1.14E-1 | 9.26E-2 | 1.09E-1 |
| Monitor at Dump F | 1.66E-1 | 1.25E-1 | 1.89E-1 | 1.56E-1 | 1.77E-1 |
| Monitor at Well 4 | 2.06E-1 | 1.58E-1 | 2.32E-1 | 1.90E-1 | 2.19E-1 |
| Monitor at West Side | 8.88E-2 | 6.64E-2 | 1.02E-1 | 8.41E-2 | 9.45E-2 |
| Monitor at Mine Vent | 1.21E-1 | 9.40E-2 | 1.36E-1 | 1.11E-1 | 1.29E-1 |
| Moquino | 2.44E-1 | 1.91E-1 | 2.72E-1 | 2.22E-1 | 2.59E-1 |
| Paguate | 1.12E-1 | 8.53E-2 | 1.27E-1 | 1.04E-1 | 1.19E-1 |
| Seboyeta | 8.87E-2 | 6.96E-2 | 9.86E-2 | 8.01E-2 | 9.41E-2 |
| Range North | 2.70E-1 | 2.10E-1 | 3.02E-1 | 2.46E-1 | 2.87E-1 |
| Range South | 7.07E-2 | 5.54E-2 | 7.85E-2 | 6.38E-2 | 7.49E-2 |
| Range East | 7.07E-3 | 5.55E-3 | 7.84E-3 | 6.37E-3 | 7.49E-3 |
| Range West | 3.59E-2 | 2.80E-2 | 4.01E-2 | 3.27E-2 | 3.81E-2 |
| | | Ground-Deposited Radionuclides | | | |
| Bibo | 1.50 | 1.18 | 1.71 | 1.38 | 1.60 |
| Casa Blanca | 3.17E-1 | 2.49E-1 | 3.61E-1 | 2.91E-1 | 3.38E-1 |
| Jackpile-Housing | 2.63E+1 | 2.06E+1 | 2.99E+1 | 2.41E+1 | 2.81E+1 |
| Laguna and Encinal | 2.35E-1 | 1.84E-1 | 2.68E-1 | 2.15E-1 | 2.51E-1 |
| Monitor at Dump F | 1.96E+1 | 1.54E+1 | 2.23E+1 | 1.79E+1 | 2.09E+1 |
| Monitor at Well 4 | 3.45 | 2.70 | 3.92 | 3.16 | 3.68 |
| Monitor at West Side | 1.92E+1 | 1.51E+1 | 2.19E+1 | 1.76E+1 | 2.05E+1 |
| Monitor at Mine Vent | 6.49 | 5.08 | 7.38 | 5.94 | 6.91 |
| Moquino | 1.17 | 9.16E-1 | 1.33 | 1.07 | 1.25 |
| Paguate | 6.68 | 5.23 | 7.60 | 6.12 | 7.12 |
| Seboyeta | 3.19E-1 | 2.50E-1 | 3.63E-1 | 2.92E-1 | 3.40E-1 |
| Range North | 1.52 | 1.19 | 1.73 | 1.39 | 1.62 |
| Range South | 2.20 | 1.73 | 2.51 | 2.02 | 2.35 |
| Range East | 1.57E-2 | 1.23E-2 | 1.79E-2 | 1.44E-2 | 1.68E-2 |
| Range West | 3.26E-1 | 2.55E-1 | 3.71E-1 | 2.99E-1 | 3.48E-1 |

Table 3.13. 70-Year Population Dose Commitments under Alternative A for Area within 80 km of Mine Site (organ-rem/yr)

| Organ or Tissue | Inhalation: Particulates | Inhalation: Radon | Ingestion | External: Ground | External: Cloud | Total |
|---|---|---|---|---|---|---|
| Bronchial epithelium | | 1.22E+2 | | | | 1.22E+2 |
| Nasopharyngeal | 8.71E+1 | | | | | 8.71E+1 |
| Tracheobronchial | 3.88E-2 | | | | | 3.88E-2 |
| Pulmonary | 1.65E+1 | | | 1.35E+1 | 8.45E-1 | 3.08E+1 |
| Whole body | 6.86E+1 | | 1.05E+1 | 1.43E+1 | 8.96E-1 | 2.65E+1 |
| Bone | 2.10E+1 | | 9.77E+1 | 1.67E+1 | 1.01 | 1.36E+2 |
| Kidney | 6.23E+1 | | 6.41E+1 | | | 7.04E+1 |
| Liver | 1.48E+1 | | 1.91E+1 | | | 2.05E+1 |
| Stomach | 4.62E-2 | | | | | 4.62E-2 |
| Small intestine | 1.06E-2 | | | 1.07E+1 | 6.76E-1 | 1.14E+1 |
| Upper large intestine | 8.55E-2 | | | | | 8.55E-2 |
| Lower large intestine | 7.70E-2 | | | | | 7.70E-2 |
| Lymph nodes | 7.65E+2 | | | | | 7.65E+2 |
| Skin | | | | 1.70E+2 | 3.34 | 1.73E+2 |
| Ovaries | | | | 1.06E+1 | 6.61E-1 | 1.12E+1 |
| Testes | | | | 1.23E+1 | 7.65E-1 | 1.31E+1 |
| Red marrow | | | | 1.53E+1 | 9.41E-1 | 1.62E+1 |
| Spleen | | | | 1.40E+1 | 8.82E-1 | 1.49E+1 |

The environmental dose commitments (Table 3.14) were calculated for 100 years because contamination of the environment by long-lived radionuclides represents a long-term potential source of exposure to humans. The phrase "environmental dose commitment" actually refers to the total radiation dose to all individuals over the entire period that the material persists in the environment and interacts with man. The period of the interaction of the long-lived radionuclides is proportional to their half-lives and persistence (i.e., availability) in the environment. Theoretically, the correct period for integration is an infinite time. Thus, the 100-year period used here is less than the period of potential interaction of the released radionuclides with man, but it is consistent with present regulatory procedures (USNRC 1980).

### 3.5.2 Alternatives B-D

Under Alternatives B through D, the sources of particulates would be covered, and the contribution of particulates from the mine site to dose commitments would be comparable to background levels from an equal surface area in the region. The only source of elevated exposure would be from exhalation of radon through the soil cover over the radioactive materials, and the dose commitments would be limited to those to bronchial epithelium. For Alternative B, the dose commitments to bronchial epithelium would be 59% of those under Alternative A; for Alternatives C1 through D, the dose commitments would be reduced to 8% of Alternative A values. If the entire mine site were covered with soil to the depths specified under Alternatives B through D, the dose commitments would be reduced only to 7% of Alternative A values.

## 3.6 SUMMARY AND DISCUSSION

In this chapter, hydrospheric and atmospheric pathways of exposures were analyzed for five alternative plans for decommissioning of the Jackpile-Paguate mines.

The analysis of potential impacts of the hydrospheric pathway indicated that this would not be a significant route of human exposure under any of the decommissioning alternatives. The groundwater supplies of Laguna most likely would not be affected within at least the next 100 years, irrespective of the decommissioning alternative selected.

Surface water is not presently used as a source of potable water in the communities up to 20 km downstream from the mine complex; however, water from the Paguate Reservoir is drunk by grazing livestock that could be consumed by humans. The radionuclides in the reservoir are from material transported in the runoff from the watersheds above and below the mine complex, as well as from the mine site. In addition, part of the flow of the Rio Paguate and Rio Moquino is from groundwater discharge both upstream and within the mine area and could include locally contaminated groundwater. The transport of radionuclides by surface runoff would continue under Alternative A but would be mostly eliminated under Alternatives B through D. Therefore, it is anticipated that surface water quality would improve after implementation of Alternatives B through D.

It is surmised that the quantity of groundwater discharged into local streams would increase with increased depth of backfill in the mine pits. This is

Table 3.14. 100-Year Environmental Dose Commitments under Alternative A for Area within 80 km of Mine Site (organ-rem)

| Organ or Tissue | Inhalation | | Ingestion | External | | Total |
|---|---|---|---|---|---|---|
| | Particulates | Radon | | Ground | Cloud | |
| Bronchial epithelium | | 1.21E+4 | | | | 1.21E+4 |
| Nasopharyngeal | 8.67E+3 | | | | | 8.67E+3 |
| Tracheobronchial | 3.86 | | | | | 3.86 |
| Pulmonary | 1.63E+3 | | | 2.01E+3 | 8.37E+1 | 3.72E+3 |
| Whole body | 6.81E+1 | | 1.14E+3 | 2.14E+3 | 8.88E+1 | 3.43E+3 |
| Bone | 2.08E+3 | | 1.02E+4 | 2.49E+3 | 1.00E+2 | 1.49E+4 |
| Kidney | 6.18E+2 | | 8.79E+3 | | | 9.40E+3 |
| Liver | 1.47E+2 | | 2.61E+3 | | | 2.76E+3 |
| Stomach | 4.58 | | | | | 4.58 |
| Small intestine | 1.05 | | | 1.60E+3 | 6.70E+1 | 1.67E+3 |
| Upper large intestine | 8.48 | | | | | 8.48 |
| Lower large intestine | 7.63 | | | | | 7.63 |
| Lymph nodes | 7.59E+4 | | | | | 7.59E+4 |
| Skin | | | | 2.52E+4 | 3.31E+2 | 2.56E+4 |
| Ovaries | | | | 1.58E+3 | 6.54E+1 | 1.64E+3 |
| Testes | | | | 1.84E+3 | 7.58E+1 | 1.91E+3 |
| Red marrow | | | | 2.28E+3 | 9.31E+1 | 2.38E+3 |
| Spleen | | | | 2.10E+3 | 8.73E+1 | 2.18E+3 |

because backfilling of the pits would reduce evaporation and thus result in increased groundwater levels over a long period (several hundred years). The concentrations of radionuclides might decrease over a long period as a result of removal of the higher specific activity ore by the past mining of the Jackpile-Paguate ore zone.

It was determined that the atmospheric pathways (inhalation of airborne radionuclides, ingestion of food contaminated by deposition of radionuclides, and external exposures) would result in human exposure and would be greatly influenced by choice of decommissioning alternative.

The regulatory limits on airborne concentrations of radionuclides in the uranium series above the levels of natural background are given in the Code of Federal Regulations (10 CFR Part 40, Appendix B, 1975). The lowest limit, that for Th-230, is $8 \times 10^{-2}$ pCi/m$^3$ for soluble thorium and $3 \times 10^{-1}$ pCi/m$^3$ for insoluble thorium. The predicted concentrations of Th-230 at five sites, four on the mine site close to the lease boundaries and one at Paguate (the closest town to the mine boundary), are shown in Table 3.15. Comparison of the concentrations shown in the table with the limits specified in 10 CFR Part 40 indicate that the regulatory limits for thorium would not be exceeded even if Alternative A (No-Action Case) were implemented. Under this alternative, the mine site would not be reclaimed, only fenced to exclude public access.

The suggested concentration limit for radon (Rn-222) in air at the site boundary is 1000 pCi/m$^3$ (1 pCi/L) for regions of high population density (such as near a town) and 3000 pCi/m$^3$ (3 pCi/L) for regions of low population density (such as the northern, southern, and eastern boundaries of the mine complex). This analysis indicates that the radon concentrations near the mine boundaries and at Paguate (Table 3.15) would not exceed the regulatory limits even under Alternative A conditions.

Table 3.15. Estimated Concentrations (pCi/m$^3$) of Thorium, Radon, and Working Level at Site Boundaries and at Nearest Town under Alternative A Conditions

| Site | Th-230†[1] | Rn-222 | mWL†[2] |
|---|---|---|---|
| Monitor at Dump F | $2.25 \times 10^{-3}$ | 80.6 | 0.31 |
| Monitor at Well #4 | $5.79 \times 10^{-4}$ | 60.9 | 0.32 |
| Monitor at West Side | $1.52 \times 10^{-3}$ | 104.0 | 0.20 |
| Monitor at Mine Vent | $9.47 \times 10^{-4}$ | 290.0 | 0.17 |
| Paguate | $9.67 \times 10^{-4}$ | 44.9 | 0.19 |

†[1] Because of secular radioactive equilibrium, the concentrations of the other particulate radionuclides would be equal to those of Th-230.

†[2] mWL = 0.001 WL.

The limit suggested by the Environmental Protection Agency (USEPA 1982) for radon decay product concentration (working level), including background, is 15 mWL. The background working level for outdoor conditions in the region around the mine complex is about 0.3 mWL, and for indoor conditions the working level would not exceed 0.5 mWL. Thus, the EPA limit would not be exceeded.

Under Alternative B and Alternatives C1-D, radon concentrations would be reduced to 59% and 8%, respectively, of Alternative A values, and thus would be well within the suggested limits.

The dose rates and doses to individuals, the dose commitments to individuals and populations, and the environmental dose commitments for the atmospheric pathway were calculated for all towns individually or as part of a larger urban area (25 selected locations) within 80 km (50 mi) of the mine site under Alternative A conditions. It was determined that exposures from radionuclides released from the mine site under the other alternatives would be negligible except for exposure to radon progeny. Under Alternative B, the dose rate and dose to bronchial epithelium from radon would be 59% of the exposures under Alternative A; the exposures under Alternatives C1 through D would be 8% of those for Alternative A. Radon decay products would contribute about 52% of the radiation dose to the lung in the first five years of irradiation, decreasing to about 34% in the period 90-95 years after decommissioning. Thus, under Alternatives B through D, the doses to lung would also reduce to about 4% (4.2% to 2.7%) of the doses under Alternative A. The dose to the other organs under Alternatives B through D would decrease to less than 0.1% of the doses that could be received under Alternative A.

The Code of Federal Regulations (40 CFR Part 190) limits exposure for uranium fuel cycle facilities to individual dose commitments of no more than 25 mrem/yr to any organ from all pathways of exposure (exclusive of radon short-lived decay products). However, uranium mining operations are specifically excluded from this limit (U.S. EPA 40 CFR 190.02: Definitions, Part VII, January 13, 1977, "Environmental Radiation Protection Standards for Nuclear Power Operations"). Despite this exclusion, however, the doses predicted for the Jackpile-Paguate decommissioning alternatives have been compared with the 40 CFR 190 limits to place potential exposures in perspective.

For the inhalation pathway, the two largest individual 70-year dose commitments under Alternative A would be those to the lymph nodes (248 mrem/yr) and those to the nasopharyngeal region of the lungs (29.4 mrem/yr) of residents of Paguate, the nearest town to the site. The individual dose commitment to bone of Paguate residents for the inhalation pathway would be 6.7 mrem/yr. The largest individual dose commitments for the ingestion pathway (again to Paguate residents) would be 1.1 mrem/yr whole body, 10.4 mrem/yr bone, 6.7 mrem/yr kidney, and 2 mrem/yr liver. The largest 70-year dose commitment for external exposure would be to 107 mrem/yr to skin from ground-deposited radionuclides, in contrast to an individual dose commitment of 0.46 mrem/yr to skin from external exposure to airborne radionuclides.

The total dose commitment from all pathways of exposure--inhalation, ingestion, and external exposures--thus would exceed 25 mrem/yr to most organs under Alternative A conditions. However, because the sources of particulates would be controlled to near background levels, dose commitments would not exceed 25 mrem/yr under Alternatives B through D.

These analyses were based on a set of input parameters either extracted from data provided by Anaconda, U.S. Department of the Interior, or published in the open literature for conditions similar to those at the Jackpile-Paguate mines. In cases where data were not available, the input parameters were subjectively selected. Care was exercised not to select overly conservative values. Nevertheless, because of the magnitude of uncertainty in the input values and the use of dispersion models fitted to flat topography, the uncertainty in the values reported in this section could be a factor of five.

The procedures followed in these analyses did not include consideration of possible breaching of the integrity of decommissioned land by either water or wind erosion (see Figs. 3.25 and 3.26). If the integrity of the reclaimed surfaces is not maintained and the surface covers are removed, the exposures still would most likely be less than those under Alternative A. In such a case, the most affected exposure pathway would be surface water transport of radionuclides; subsequent accumulation of higher specific activity sediments would be expected in and above the Paguate Reservoir and on adjacent forage lands.

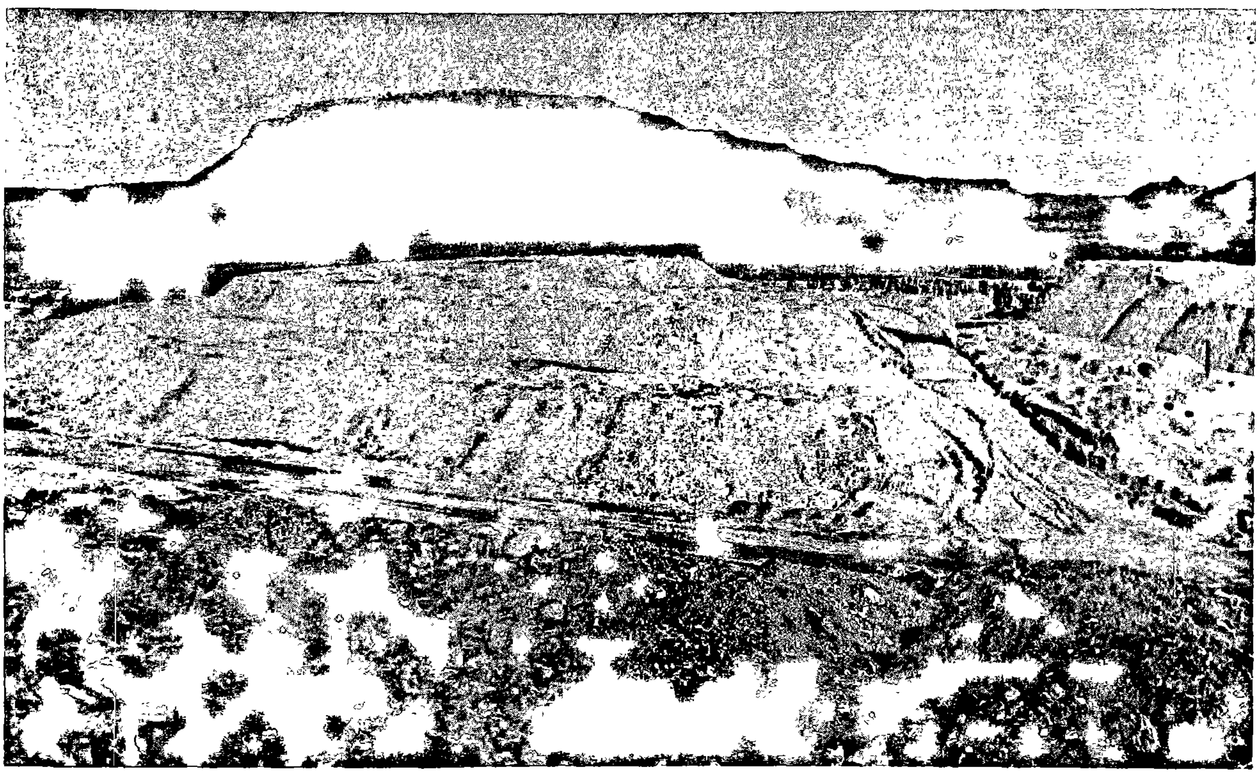


Figure 3.25. Photograph Showing Water Erosion of Jackpile Sandstone (light-colored material in center of photograph). (Gavilan Mesa is in the background.)

Figure 3.26. Photograph Showing Water Erosion at Several Locations on the Side of the "T" Waste Pile (upper portion of photograph). (This photograph was taken from the "U" Waste Pit on January 14, 1983. The Rio Moquino runs between the two waste piles. Erosion of the banks of the stream is also evident.)

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# 4. HEALTH EFFECTS

## 4.1 INTRODUCTION

In this section, potential radiation-induced somatic effects (diseases inflicting an individual) and genetic effects (diseases inflicting the offspring of the irradiated individual) from exposure to radiation released from the Jackpile-Paguate mines are discussed. A computer code developed at Argonne National Laboratory, "Potential Radiation-Induced Biological Effects in Man" (PRIM) (Momeni 1983a, 1983b), was used in the analyses. The code is based on dynamic changes of attrition (natural- and radiation-induced causes of death) and renewal (birth), and the lifetable method. The effects of population migration (in-migration and out-migration) were not incorporated into the analyses.

The present population of towns within 80 km (50 mi) of the Jackpile-Paguate mine complex was estimated to be 362,100 people (Table 4.1). For this analysis, the population of each town was grouped into 19 cohorts of five-year age intervals. Each cohort was further subdivided by sex. The age distribution* of the entire regional population (based on the average characteristics of the total population of the United States) is presented in Table 4.2.

In these analyses the changes in the population structure were only effected by age-specific death rates and age-specific birth rates. The total birth rate for each age cohort in each time period was calculated from age-specific fertility rates (Table 4.2). The numbers of male and female newborns were calculated from the 1970 average sex ratios of newborns in the United States. Survival of members of each age subgroup during each time interval is dependent upon both the age-specific and time-specific probability of survival to the next time interval in the presence of all forces of mortality. In these analyses the possibility of death from natural causes was assumed to be independent of time. Weighted average age-specific probability of mortality was computed from the age-specific death rates for each sex and race (Table 4.2). The age-specific death rates from each neoplasm are based on data from 1969-1971 for the U.S. population as a whole.

## 4.2 PATTERN OF MORTALITY FROM SPONTANEOUS NEOPLASMS

The neoplasms individually considered in these analyses were leukemia, cancer of the lung, stomach, intestine, breast, bone, pancreas and liver, urinary and sex organs, and lymphoma. All other neoplasms were combined into one category.

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*The effect of racial distribution, an option available in PRIM code, was not considered. Characterization of the population on the basis of racial composition, even as Native American or non-Native American, is complex and beyond the scope of this work. However, age-specific fertility rate, age-specific death rate, and spontaneous incidence of neoplasms are not equal between the races and influence the magnitude of the projections presented here.

Table 4.1. Populations of Towns within 80 km of Jackpile-Paguate Mine Complex

| Town | Distance (km)†[1] X | Distance (km)†[1] Y | Population Size |
|---|---|---|---|
| Albuquerque | 60 | 0 | 330,000 |
| Belen | 60 | -40 | 5,600 |
| Bibo | - 2 | 3 | 200 |
| Bluewater | -60 | 30 | 500 |
| Casa Blanca | -10 | -10 | 1,000 |
| Cubero | -16 | -10 | 200 |
| Grants-Millan | -40 | 0 | 15,500 |
| Laguna | -5 | 10 | 1,650 |
| Los Luna | 60 | -30 | 1,200 |
| Mesita | 3 | -12 | 750 |
| Moquino | 1.5 | 5 | 250 |
| Paguate | 3 | 1 | 1,150 |
| San Fidel | -25 | 0 | 500 |
| San Mateo | -20 | 30 | 250 |
| Seboyeta | 0 | 10 | 250 |

†[1] The "x" axis represents east-west, with a negative sign indicating west; the "y"axis represents north-south, with a negative sign indicating south. The origin of the coordinate system (x = 0, y = 0) is the confluence of the Rio Paguate and Rio Moquino near the center of the mine site.

Age-specific mortality from spontaneous incidence of neoplasms was calculated for each sex and for each successive five-year time interval for the next 90 years. Table 4.3 contains, as an example, a list of age-specific mortalities from spontaneous incidence of neoplasms and from other causes of death for the period 50 to 55 years from now. Comparison of the data in Tables 4.2 and 4.3 indicates that over the 55-year period, the age-distribution for each sex would change and the size of some of the age cohorts would increase. The data in Table 4.3 also indicate that incidence of some diseases is more frequent in one sex than the other; for example, death from breast cancer is more common among females, even though it does occur in males, but with lower incidence. Furthermore, the death rate from neoplasms varies among the different age groups and is not a constant fraction of other causes of death.

A summary of death from spontaneous neoplasms over the entire regional population for the 90-year period is given in Table 4.4. Also given is the ratio of deaths from neoplasms to total deaths from all causes of mortality. The ratio increases from about 21% to about 23% during the 90-year period. As shown in the table, the largest cause of death from spontaneous incidence of neoplasm is cancer of the digestive system; the second largest cause is cancer of the respiratory system. The incidence of neoplasms in the respiratory system has steadily increased from $3 \times 10^{-3}$ in 1930 to $5 \times 10^{-2}$ for males and $1 \times 10^{-2}$

Table 4.2. Regional Population Characteristics

| Age | AGSF†[1] | | AGDR†[2] | | Population | |
|---|---|---|---|---|---|---|
| | Male | Female | Male | Female | Male | Female |
| 5 | 0.0 | 0.0 | 2.569E-3 | 2.028E-3 | 15,420 | 14,820 |
| 10 | 0.0 | 0.0 | 1.826E-3 | 1.225E-3 | 17,960 | 17,290 |
| 15 | 1.100E-3 | 5.200E-3 | 1.877E-3 | 1.070E-3 | 18,730 | 18,030 |
| 20 | 6.740E-2 | 1.477E-1 | 5.781E-3 | 2.254E-3 | 17,030 | 16,690 |
| 25 | 1.506E-1 | 2.027E-1 | 8.146E-3 | 2.657E-3 | 13,960 | 14,920 |
| 30 | 1.348E-1 | 1.363E-1 | 7.069E-3 | 2.993E-3 | 11,680 | 12,080 |
| 35 | 6.760E-2 | 7.960E-2 | 7.754E-3 | 3.949E-3 | 9,855 | 10,280 |
| 40 | 2.870E-2 | 4.190E-2 | 1.086E-2 | 6.154E-3 | 9,554 | 10,030 |
| 45 | 7.100E-3 | 1.250E-2 | 1.756E-2 | 9.558E-3 | 10,300 | 10,880 |
| 50 | 4.000E-4 | 1.000E-3 | 2.854E-2 | 1.552E-2 | 10,370 | 11,110 |
| 55 | 0.0 | 0.0 | 4.554E-2 | 2.326E-2 | 9,493 | 10,230 |
| 60 | 0.0 | 0.0 | 7.247E-2 | 3.443E-2 | 8,460 | 9,266 |
| 65 | 0.0 | 0.0 | 1.087E-1 | 5.049E-2 | 7,144 | 8,176 |
| 70 | 0.0 | 0.0 | 1.564E-1 | 7.772E-2 | 5,535 | 6,891 |
| 75 | 0.0 | 0.0 | 2.212E-1 | 1.269E-1 | 4,111 | 5,574 |
| 80 | 0.0 | 0.0 | 3.174E-1 | 2.108E-1 | 2,777 | 4,054 |
| 85 | 0.0 | 0.0 | 4.314E-1 | 3.281E-1 | 1,551 | 2,511 |
| 90 | 0.0 | 0.0 | 5.597E-1 | 5.110E-1 | 956 | 1,725 |
| 95 | 0.0 | 0.0 | 3.867E-3 | 1.168E-3 | 956 | 1,725 |

†[1] Age-Specific Fertility (AGSF)

†[2] Age-Specific Death Rate (AGDR)

Table 4.3. Age-Specific Regional Mortality Rate for the Five-Year Period 2032 to 2037 from Natural Incidence of Neoplasms and other Causes

| Age | Population Size | Neoplasms†[1] | | | | | | | | | | Other Deaths |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | CA-1 | CA-2 | CA-3 | CA-4 | CA-5 | CA-6 | CA-7 | CA-8 | CA-9 | CA-10 | |
| **Males** | | | | | | | | | | | | |
| 5 | 2.19E+04 | 2.86 | 5.96E-02 | 0.0 | 1.78E-01 | 0.0 | 5.22E-02 | 1.48E-02 | 1.48E-02 | 1.48E-02 | 5.04 | 5.61E+01 |
| 10 | 2.10E+04 | 2.93 | 7.62E-02 | 0.0 | 9.45E-02 | 0.0 | 1.61E-01 | 0.0 | 0.0 | 0.0 | 4.70 | 3.83E+01 |
| 15 | 2.17E+04 | 2.19 | 1.20E-02 | 0.0 | 1.28E-01 | 0.0 | 5.95E-01 | 0.0 | 0.0 | 0.0 | 3.94 | 4.08E+01 |
| 20 | 1.89E+04 | 2.06 | 3.98E-02 | 1.71E-02 | 3.50E-01 | 0.0 | 1.24 | 1.14E-02 | 1.14E-02 | 1.14E-02 | 6.11 | 1.09E+02 |
| 25 | 1.89E+04 | 2.86 | 3.84E-01 | 1.40E-01 | 1.06 | 0.0 | 8.20E-01 | 6.82E-02 | 6.82E-02 | 6.82E-02 | 9.12 | 1.54E+02 |
| 30 | 1.95E+04 | 2.03 | 7.02E-01 | 2.65E-01 | 1.53 | 8.32E-03 | 2.73E-01 | 1.33E-01 | 1.33E-01 | 1.33E-01 | 1.09E+01 | 1.38E+02 |
| 35 | 1.91E+04 | 2.82 | 3.08 | 1.08 | 4.06 | 9.71E-03 | 3.14E-01 | 1.36E-01 | 1.36E-01 | 1.36E-01 | 1.79E+01 | 1.48E+02 |
| 40 | 1.75E+04 | 2.61 | 9.09 | 2.03 | 6.51 | 9.14E-03 | 1.28E-01 | 6.58E-01 | 6.58E-01 | 6.58E-01 | 2.74E+01 | 1.90E+02 |
| 45 | 1.52E+04 | 2.45 | 2.56E+01 | 3.21 | 1.37E+01 | 9.93E-02 | 4.19E-01 | 1.55 | 1.55 | 1.55 | 5.38E+01 | 2.67E+02 |
| 50 | 1.45E+04 | 3.79 | 4.52E+01 | 8.36 | 3.07E+01 | 1.52E-01 | 5.46E-01 | 3.00 | 3.00 | 3.00 | 9.82E+01 | 4.13E+02 |
| 55 | 1.64E+04 | 5.62 | 9.66E+01 | 1.42E+01 | 6.10E+01 | 7.40E-01 | 1.35 | 6.75 | 6.75 | 6.75 | 1.95E+02 | 7.47E+02 |
| 60 | 1.64E+04 | 9.32 | 1.49E+02 | 2.32E+01 | 9.91E+01 | 4.11E-01 | 1.78 | 1.08E+01 | 1.08E+01 | 1.08E+01 | 2.91E+02 | 1.19E+03 |
| 65 | 1.38E+04 | 1.17E+01 | 1.67E+02 | 3.27E+01 | 1.22E+02 | 7.53E-01 | 2.80 | 1.55E+01 | 1.55E+01 | 1.55E+01 | 3.40E+02 | 1.50E+03 |
| 70 | 1.02E+04 | 1.38E+01 | 1.52E+02 | 3.44E+01 | 1.18E+02 | 6.27E-01 | 1.87 | 1.80E+01 | 1.80E+01 | 1.80E+01 | 3.32E+02 | 1.59E+03 |
| 75 | 7.22E+03 | 1.52E+01 | 1.18E+02 | 3.32E+01 | 1.11E+02 | 8.29E-01 | 1.26 | 1.92E+01 | 1.92E+01 | 1.92E+01 | 3.09E+02 | 1.60E+03 |
| 80 | 4.78E+03 | 1.50E+01 | 7.56E+01 | 2.71E+01 | 9.37E+01 | 6.26E-01 | 1.36 | 1.98E+01 | 1.98E+01 | 1.98E+01 | 2.51E+02 | 1.52E+03 |
| 85 | 3.19E+03 | 1.17E+01 | 4.40E+01 | 2.39E+01 | 7.14E+01 | 3.73E-01 | 9.44E-01 | 1.76E+01 | 1.76E+01 | 1.76E+01 | 1.68E+02 | 1.38E+03 |
| 90 | 1.98E+03 | 6.11 | 1.33E+01 | 1.00E+01 | 3.16E+01 | 2.09E-01 | 2.84E-01 | 1.02E+01 | 1.02E+01 | 1.02E+01 | 6.02E+01 | 1.11E+03 |
| 95 | 8.91E+02 | 9.88E-01 | 1.23 | 1.43 | 3.83 | 9.15E-03 | 5.03E-02 | 1.26 | 1.26 | 1.26 | 7.45 | 8.91E+02 |

Table 4.3. (Continued)

| Age | Population Size | Neoplasms†[1] CA-1 | CA-2 | CA-3 | CA-4 | CA-5 | CA-6 | CA-7 | CA-8 | CA-9 | CA-10 | Other Deaths |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Females | | | | | | | | | | | | |
| 5 | 2.11E+04 | 2.24 | 5.85E-02 | 0.0 | 5.24E-02 | 0.0 | 1.32E-01 | 1.43E-02 | 1.43E-02 | 1.43E-02 | 3.73 | 4.28E+01 |
| 10 | 2.03E+04 | 2.55 | 1.84E-02 | 0.0 | 3.68E-02 | 0.0 | 1.85E-01 | 0.0 | 0.0 | 0.0 | 3.26 | 2.49E+01 |
| 15 | 2.10E+04 | 1.55 | 1.21E-02 | 0.0 | 3.64E-02 | 0.0 | 3.65E-01 | 0.0 | 0.0 | 0.0 | 3.26 | 2.25E+01 |
| 20 | 1.83E+04 | 1.54 | 1.70E-02 | 0.0 | 9.96E-02 | 0.0 | 4.34E-01 | 1.10E-02 | 1.10E-02 | 1.10E-02 | 3.33 | 4.12E+01 |
| 25 | 1.84E+04 | 1.54 | 1.73E-01 | 1.67E-01 | 4.68E-01 | 3.59E-01 | 2.54E-01 | 6.63E-02 | 6.63E-02 | 6.63E-02 | 6.05 | 4.89E+01 |
| 30 | 1.90E+04 | 1.39 | 2.27E-01 | 2.25E-01 | 1.31 | 2.52 | 1.67E-01 | 1.30E-01 | 1.30E-01 | 1.30E-01 | 1.07E+01 | 5.69E+01 |
| 35 | 1.88E+04 | 1.43 | 7.80E-01 | 2.77E-01 | 2.22 | 6.80 | 1.15E-01 | 1.33E-01 | 1.33E-01 | 1.33E-01 | 1.63E+01 | 7.41E+01 |
| 40 | 1.72E+04 | 2.16 | 4.39 | 1.40 | 5.65 | 1.28E+01 | 4.68E-01 | 6.48E-01 | 6.48E-01 | 6.48E-01 | 3.59E+01 | 1.06E+02 |
| 45 | 1.51E+04 | 2.42 | 7.63 | 1.96 | 1.01E+01 | 2.22E+01 | 5.28E-01 | 1.54 | 1.54 | 1.54 | 5.86E+01 | 1.44E+02 |
| 50 | 1.43E+04 | 2.93 | 1.29E+01 | 3.15 | 1.82E+01 | 3.16E+01 | 3.99E-01 | 2.97 | 2.97 | 2.97 | 8.51E+01 | 2.23E+02 |
| 55 | 1.65E+04 | 5.42 | 2.24E+01 | 5.81 | 3.74E+01 | 5.10E+01 | 5.28E-01 | 6.79 | 6.79 | 6.79 | 1.47E+02 | 3.84E+02 |
| 60 | 1.68E+04 | 6.63 | 2.94E+01 | 9.64 | 6.14E+01 | 5.90E+01 | 1.12 | 1.11E+01 | 1.11E+01 | 1.11E+01 | 1.97E+02 | 5.80E+02 |
| 65 | 1.51E+04 | 7.96 | 2.69E+01 | 1.31E+01 | 7.81E+01 | 5.57E+01 | 1.19 | 1.69E+01 | 1.69E+01 | 1.69E+01 | 2.20E+02 | 7.60E+02 |
| 70 | 1.28E+04 | 1.06E+01 | 2.68E+01 | 1.58E+01 | 9.40E+01 | 5.34E+01 | 1.13 | 2.28E+01 | 2.28E+01 | 2.28E+01 | 2.36E+02 | 9.96E+02 |
| 75 | 9.59E+03 | 1.12E+01 | 2.32E+01 | 1.85E+01 | 9.62E+01 | 4.34E+01 | 1.90 | 2.55E+01 | 2.55E+01 | 2.55E+01 | 2.21E+02 | 1.22E+03 |
| 80 | 7.15E+03 | 9.64 | 1.81E+01 | 1.99E+01 | 9.22E+01 | 4.02E+01 | 9.87E-01 | 2.96E+01 | 2.96E+01 | 2.96E+01 | 1.86E+02 | 1.51E+03 |
| 85 | 5.53E+03 | 9.89 | 1.41E+01 | 1.81E+01 | 8.13E+01 | 3.31E+01 | 6.62E-01 | 3.05E+01 | 3.05E+01 | 3.05E+01 | 1.51E+02 | 1.81E+03 |
| 90 | 4.05E+03 | 5.24 | 7.36 | 1.08E+01 | 4.53E+01 | 1.73E+01 | 5.41E-01 | 2.09E+01 | 2.09E+01 | 2.09E+01 | 8.10E+01 | 2.07E+03 |
| 95 | 2.04E+03 | 2.20 | 9.74E-01 | 1.40 | 6.69 | 3.60 | 1.03E-01 | 2.89 | 2.89 | 2.89 | 1.30E+01 | 2.04E+03 |

†[1] CA-1 = leukemia, CA-2 = lung cancer, CA-3 = stomach cancer, CA-4 = intestinal cancer, CA-5 = breast cancer, CA-6 = bone cancer, CA-7 = liver plus pancreatic cancer, CA-8 = cancer of urinary organs, sex organs, CA-9 = lymphoma, CA-10 = all other neoplasms not listed in CA-1 to CA-9, CAS = total of all cancers.

Table 4.4. Cumulative Spontaneous Cancer Mortality for Five-Year Intervals for the Regional Population

| Time (Years) | Neoplasms†[1] | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | CA-1 | CA-2 | CA-3 | CA-4 | CA-5 | CA-6 | CA-7 | CA-8 | CA-9 | CA-10 | CAS | CAS/Death |
| 5 | 116.9 | 609.2 | 181.6 | 762.7 | 249.7 | 16.4 | 157.2 | 157.2 | 157.2 | 2,156.9 | 4,564.9 | 0.207 |
| 10 | 128.2 | 667.4 | 202.6 | 849.0 | 272.2 | 18.0 | 176.7 | 176.7 | 176.7 | 2,376.9 | 5,044.3 | 0.212 |
| 15 | 140.5 | 719.4 | 224.0 | 934.7 | 293.6 | 19.2 | 198.2 | 198.2 | 198.2 | 2,588.9 | 5,514.8 | 0.206 |
| 20 | 151.9 | 762.0 | 242.9 | 1,008.4 | 313.1 | 20.2 | 217.2 | 217.2 | 217.2 | 2,773.5 | 5,923.7 | 0.203 |
| 25 | 161.8 | 798.5 | 259.3 | 1,071.1 | 332.8 | 21.1 | 233.7 | 233.7 | 233.7 | 2,936.1 | 6,282.0 | 0.206 |
| 30 | 170.1 | 835.9 | 273.0 | 1,125.7 | 353.6 | 22.2 | 247.5 | 247.5 | 247.5 | 3,087.2 | 6,610.2 | 0.212 |
| 35 | 176.8 | 881.0 | 285.1 | 1,177.9 | 375.1 | 23.3 | 258.8 | 258.8 | 258.8 | 3,239.4 | 6,934.9 | 0.217 |
| 40 | 183.5 | 939.4 | 297.4 | 1,234.5 | 395.7 | 24.4 | 268.5 | 268.5 | 268.5 | 3,406.7 | 7,287.1 | 0.210 |
| 45 | 191.0 | 1,011.7 | 312.1 | 1,302.1 | 414.5 | 25.6 | 278.4 | 278.4 | 278.4 | 3,602.8 | 7,695.2 | 0.220 |
| 50 | 201.3 | 1,093.3 | 332.5 | 1,389.8 | 433.8 | 27.3 | 292.8 | 292.8 | 292.8 | 3,845.6 | 8,202.0 | 0.225 |
| 55 | 216.0 | 1,173.4 | 360.8 | 1,500.9 | 456.3 | 29.3 | 316.4 | 316.4 | 316.4 | 4,131.8 | 8,817.5 | 0.232 |
| 60 | 233.3 | 1,240.3 | 392.5 | 1,619.8 | 482.2 | 30.9 | 347.4 | 347.4 | 347.4 | 4,421.3 | 9,462.4 | 0.234 |
| 65 | 248.7 | 1,287.9 | 419.0 | 1,719.8 | 506.1 | 32.1 | 376.9 | 376.9 | 376.9 | 4,657.0 | 10,001.1 | 0.232 |
| 70 | 258.5 | 1,317.9 | 435.8 | 1,783.2 | 523.1 | 33.0 | 396.5 | 396.5 | 396.5 | 4,802.4 | 10,343.5 | 0.229 |
| 75 | 262.5 | 1,340.6 | 442.5 | 1,810.2 | 532.8 | 33.6 | 403.8 | 403.8 | 403.8 | 4,870.1 | 10,503.7 | 0.227 |
| 80 | 263.9 | 1,368.2 | 444.6 | 1,822.5 | 539.1 | 34.2 | 403.0 | 403.0 | 403.0 | 4,923.4 | 10,604.9 | 0.226 |
| 85 | 267.7 | 1,405.8 | 450.7 | 1,851.6 | 548.3 | 34.9 | 404.0 | 404.0 | 404.0 | 5,028.6 | 10,799.6 | 0.229 |
| Total | 3,372.6 | 17,451.9 | 5,556.3 | 22,963.8 | 7,021.8 | 445.6 | 4,977.1 | 4,977.1 | 4,977.1 | 62,848.7 | 134,591.8 | |

†[1] CA-1 = leukemia, CA-2 = lung cancer, CA-3 = stomach cancer, CA-4 = intestinal cancer, CA-5 = breast cancer, CA-6 = bone cancer, CA-7 = liver plus pancreatic cancer, CA-8 = cancer of urinary organs, sex organs, CA-9 = lymphoma, CA-10 = all other neoplasms not listed in CA-1 to CA-9, CAS = total of all cancers, CAS/Death = ratio of spontaneous cancer cumulative mortality to all death.

for females in 1970. The trend in incidence of diseases could be related to several factors, including changes in the environment. Attempts to predict the future incidence of neoplasms only on the basis of past trends could produce erroneous results. The increase in total cancer mortality with time, as shown in Table 4.4, is due in part to an increase in the size of the population and in part to changes in the population age distribution.

## 4.3 PATTERN OF MORTALITY FROM RADIATION-INDUCED NEOPLASMS

Potential mortality as a result of radiation-induced neoplasms was calculated on the basis of the total radiation doses from exposures to mine emissions along the pathways of irradiation depicted in Figure 3.3.

Similar to the spontaneous incidence of neoplasms, age-specific mortality from each type of radiation-induced neoplasm in the presence of all the other causes of mortality was calculated. The probability of radiation-induced mortality from each type of neoplasm was calculated by both "absolute risk" and "relative risk" models (NAS 1972; USNRC 1975). The age- and sex-specific parameters for these models are those recommended in BEIR III ( NAS 1980). In addition to being dependent on the magnitude of the radiation dose, the absolute risk model is dependent on age, sex, and the type of neoplasm. The dependence on the radiation dose is expressed by a linear-quadratic function. The relative risk model is dependent on dose, age, sex, type of neoplasm, and the rate of spontaneous incidence of the same neoplasm.

For each model, the potential radiation-induced mortalities were calculated from age-specific incidence of each type of neoplasm. Separate calculations were made for each sex and for the populations of each town in the region. As examples, the radiation-induced mortality rate for the period 50 to 55 years from now are given in Tables 4.5 and 4.6 for the absolute and relative risk models, respectively. As indicated in the tables, the age-specific death rates are smaller than unity for each type of neoplasm.

The cumulative radiation-induced mortality for both sexes and all ages for the two risk models is summarized in Tables 4.7 and 4.8 for each five-year period. Comparison of the data in these two tables indicates that the predicted leading cause of death is not the same for the two models. For the absolute risk model, the leading cause of potential mortality is leukemia; for the relative risk model, the leading cause is cancer of the urinary system. The total predicted potential mortality from all neoplasms is 95 people under the absolute risk model and 243 people under the relative risk model. The ratio of the predicted mortalities from the two models (relative/absolute) is 2.6.

## 4.4 GENETIC EFFECTS

The total number of radiation-induced genetic disorders was calculated from an equilibrium-level genetic-induction factor of $4.2 \times 10^{-8}$ disorders per mrem for dominant effects and $5.0 \times 10^{-8}$ per mrem for multifactorial genetic disorders (USNRC 1975). The doses to gonads of males and females were normalized by 0.8 and 0.2 on the basis of the reported sensitivities (NAS 1980).

The natural incidence of genetic disorders in the United States is 0.107 for each liveborn (NAS 1980). For the region of the mines, the total births

Table 4.5. Age-Specific Mortality Rate for the Five-Year Period 2032-2037 from Radiation-Induced Neoplasms for the Regional Population--Absolute Risk Model†[1]

| Age | Population Size | Neoplasms†[2] | | | | | | | | | | Other Deaths |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | CA-1 | CA-2 | CA-3 | CA-4 | CA-5 | CA-6 | CA-7 | CA-8 | CA-9 | CA-10 | |
| <u>Males</u> | | | | | | | | | | | | |
| 5 | 2.2E+04 | 1.1E-03 | 0.0 | 0.0 | 0.0 | 0.0 | 7.0E-06 | 0.0 | 0.0 | 0.0 | 0.0 | 5.6E+01 |
| 10 | 2.1E+04 | 3.4E-03 | 2.6E-05 | 6.3E-05 | 3.4E-06 | 0.0 | 2.3E-05 | 6.6E-06 | 6.2E-06 | 2.7E-06 | 8.1E-05 | 3.8E+01 |
| 15 | 2.2E+04 | 7.5E-03 | 1.3E-04 | 2.4E-04 | 1.7E-05 | 0.0 | 2.7E-05 | 3.3E-05 | 2.0E-05 | 1.4E-05 | 4.3E-04 | 4.1E+01 |
| 20 | 1.9E+04 | 4.6E-03 | 3.1E-04 | 4.6E-04 | 4.1E-05 | 0.0 | 3.1E-05 | 8.0E-05 | 4.7E-05 | 3.2E-05 | 1.0E-03 | 1.1E+02 |
| 25 | 1.9E+04 | 5.9E-02 | 6.6E-04 | 1.6E-03 | 1.7E-04 | 0.0 | 6.2E-05 | 1.7E-04 | 2.7E-04 | 6.9E-05 | 3.3E-03 | 1.5E+02 |
| 30 | 1.9E+04 | 1.0E-01 | 1.3E-03 | 2.6E-03 | 3.3E-04 | 0.0 | 8.2E-05 | 3.3E-04 | 4.8E-04 | 1.3E-04 | 6.2E-03 | 1.4E+02 |
| 35 | 1.9E+04 | 1.6E-01 | 2.0E-03 | 3.8E-03 | 5.3E-04 | 0.0 | 1.5E-04 | 5.3E-04 | 7.3E-04 | 2.1E-04 | 1.0E-02 | 1.5E+02 |
| 40 | 1.7E+04 | 2.2E-01 | 2.8E-03 | 8.1E-03 | 1.2E-03 | 0.0 | 2.3E-04 | 7.4E-04 | 1.2E-03 | 3.0E-04 | 4.4E-02 | 1.9E+02 |
| 45 | 1.5E+04 | 2.8E-01 | 3.5E-03 | 9.3E-03 | 1.5E-03 | 0.0 | 3.3E-04 | 9.2E-04 | 1.5E-03 | 3.7E-04 | 5.5E-02 | 2.7E+02 |
| 50 | 1.4E+04 | 2.6E-01 | 3.3E-03 | 8.8E-03 | 1.4E-03 | 0.0 | 3.1E-04 | 8.7E-04 | 1.4E-03 | 3.5E-04 | 5.2E-02 | 4.1E+02 |
| 55 | 1.6E+04 | 3.0E-01 | 3.8E-03 | 2.6E-02 | 4.2E-03 | 0.0 | 3.5E-04 | 9.8E-04 | 3.2E-03 | 3.9E-04 | 7.6E-02 | 7.5E+02 |
| 60 | 1.6E+04 | 2.9E-01 | 3.7E-03 | 2.6E-02 | 4.1E-03 | 0.0 | 3.4E-04 | 9.7E-04 | 3.2E-03 | 3.9E-04 | 7.5E-02 | 1.2E+03 |
| 65 | 1.4E+04 | 2.4E-01 | 3.1E-03 | 2.2E-02 | 3.4E-03 | 0.0 | 2.8E-04 | 8.1E-04 | 2.7E-03 | 3.2E-04 | 6.2E-02 | 1.5E+03 |
| 70 | 1.0E+04 | 1.7E-01 | 2.2E-03 | 1.6E-02 | 2.5E-03 | 0.0 | 2.0E-04 | 5.8E-04 | 1.9E-03 | 2.3E-04 | 4.4E-02 | 1.6E+03 |
| 75 | 7.2E+03 | 1.2E-01 | 1.5E-03 | 1.1E-02 | 1.7E-03 | 0.0 | 1.4E-04 | 3.9E-04 | 1.3E-03 | 1.6E-04 | 3.0E-02 | 1.6E+03 |
| 80 | 4.8E+03 | 7.1E-02 | 9.3E-04 | 6.8E-03 | 1.0E-03 | 0.0 | 8.4E-05 | 2.4E-04 | 8.6E-04 | 9.7E-05 | 1.9E-02 | 1.5E+03 |
| 85 | 3.2E+03 | 4.2E-02 | 5.6E-04 | 4.3E-03 | 6.3E-04 | 0.0 | 5.0E-05 | 1.5E-04 | 5.5E-04 | 5.9E-05 | 1.1E-02 | 1.4E+03 |
| 90 | 2.0E+03 | 2.1E-02 | 2.9E-04 | 2.4E-03 | 3.3E-04 | 0.0 | 2.5E-05 | 7.6E-05 | 3.1E-04 | 3.1E-05 | 5.9E-03 | 1.1E+03 |
| 95 | 8.9E+02 | 3.9E-02 | 6.1E-05 | 7.3E-04 | 7.0E-05 | 0.0 | 4.1E-06 | 1.6E-05 | 1.0E-04 | 6.6E-06 | 1.3E-03 | 8.9E+02 |

Table 4.5. (Continued)

| Age | Population Size | CA-1 | CA-2 | CA-3 | CA-4 | CA-5 | CA-6 | CA-7 | CA-8 | CA-9 | CA-10 | Other Deaths |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Neoplasms†[2] | | | | | | | | | | |
| <u>Females</u> | | | | | | | | | | | | |
| 5 | 2.1E+04 | 1.0E-03 | 0.0 | 0.0 | 0.0 | 0.0 | 6.7E-06 | 0.0 | 0.0 | 0.0 | 0.0 | 4.3E+01 |
| 10 | 2.0E+04 | 3.3E-03 | 2.5E-05 | 6.0E-05 | 3.2E-06 | 0.0 | 2.2E-05 | 6.2E-06 | 5.9E-06 | 2.6E-06 | 7.7E-05 | 2.5E+01 |
| 15 | 2.1E+04 | 7.1E-03 | 1.2E-04 | 2.2E-04 | 1.6E-05 | 8.5E-04 | 2.5E-05 | 3.1E-05 | 1.9E-05 | 1.3E-05 | 4.1E-04 | 2.2E+01 |
| 20 | 1.8E+04 | 4.3E-03 | 2.9E-04 | 4.3E-04 | 3.8E-05 | 2.0E-03 | 2.9E-05 | 7.4E-05 | 4.4E-05 | 3.0E-05 | 9.6E-04 | 4.1E+01 |
| 25 | 1.8E+04 | 5.4E-02 | 6.1E-04 | 1.5E-03 | 1.6E-04 | 4.3E-03 | 5.7E-05 | 1.6E-04 | 2.5E-04 | 6.3E-05 | 3.0E-03 | 4.9E+01 |
| 30 | 1.9E+04 | 9.2E-02 | 1.2E-03 | 2.4E-03 | 3.1E-04 | 7.5E-03 | 7.5E-05 | 3.0E-04 | 4.5E-04 | 1.2E-04 | 5.7E-03 | 5.7E+01 |
| 35 | 1.9E+04 | 1.5E-01 | 1.9E-03 | 3.5E-03 | 4.9E-04 | 1.2E-02 | 1.3E-04 | 4.8E-04 | 6.9E-04 | 1.9E-04 | 9.2E-03 | 7.4E+01 |
| 40 | 1.7E+04 | 2.0E-01 | 2.6E-03 | 7.6E-03 | 1.1E-03 | 1.7E-02 | 2.1E-04 | 6.8E-04 | 1.2E-03 | 2.7E-04 | 4.1E-02 | 1.1E+02 |
| 45 | 1.5E+04 | 2.5E-01 | 3.2E-03 | 8.7E-03 | 1.4E-03 | 2.1E-02 | 2.9E-04 | 8.4E-04 | 1.4E-03 | 3.4E-04 | 5.1E-02 | 1.4E+02 |
| 50 | 1.4E+04 | 2.4E-01 | 3.0E-03 | 8.2E-03 | 1.3E-03 | 2.0E-02 | 2.8E-04 | 7.9E-04 | 1.3E-03 | 3.2E-04 | 4.7E-02 | 2.2E+02 |
| 55 | 1.6E+04 | 2.7E-01 | 3.5E-03 | 2.5E-02 | 3.9E-03 | 2.3E-02 | 3.2E-04 | 9.1E-04 | 3.1E-03 | 3.7E-04 | 7.1E-02 | 3.8E+02 |
| 60 | 1.7E+04 | 2.8E-01 | 3.6E-03 | 2.5E-02 | 4.0E-03 | 2.3E-02 | 3.2E-04 | 9.3E-04 | 3.2E-03 | 3.7E-04 | 7.2E-02 | 5.8E+02 |
| 65 | 1.5E+04 | 2.4E-01 | 3.1E-03 | 2.2E-02 | 3.5E-03 | 2.0E-02 | 2.8E-04 | 8.1E-04 | 2.8E-03 | 3.2E-04 | 6.3E-02 | 7.6E+02 |
| 70 | 1.3E+04 | 2.0E-01 | 2.6E-03 | 1.9E-02 | 2.9E-03 | 1.7E-02 | 2.3E-04 | 6.7E-04 | 2.3E-03 | 2.7E-04 | 5.2E-02 | 1.0E+03 |
| 75 | 9.6E+03 | 1.4E-01 | 1.8E-03 | 1.3E-02 | 2.0E-03 | 1.2E-02 | 1.6E-04 | 4.7E-04 | 1.7E-03 | 1.9E-04 | 3.6E-02 | 1.2E+03 |
| 80 | 7.1E+03 | 9.1E-02 | 1.2E-03 | 9.4E-03 | 1.4E-03 | 8.3E-03 | 1.1E-04 | 3.2E-04 | 1.2E-03 | 1.3E-04 | 2.5E-02 | 1.5E+03 |
| 85 | 5.5E+03 | 6.3E-02 | 8.6E-04 | 6.8E-03 | 9.6E-04 | 6.0E-03 | 7.4E-05 | 2.2E-04 | 8.9E-04 | 9.0E-05 | 1.7E-02 | 1.8E+03 |
| 90 | 4.0E+03 | 3.8E-02 | 5.5E-04 | 4.6E-03 | 6.1E-04 | 4.0E-03 | 4.6E-05 | 1.4E-04 | 6.1E-04 | 5.8E-05 | 1.1E-02 | 2.1E+03 |
| 95 | 2.0E+03 | 9.8E-02 | 1.5E-04 | 1.7E-03 | 1.7E-04 | 1.3E-03 | 1.0E-05 | 3.8E-05 | 2.4E-04 | 1.6E-05 | 3.0E-03 | 2.0E+03 |

†[1] Risk coefficients, delay periods, and expression periods adopted from NRC 1975 and BEIR III.

†[2] CA-1 = leukemia, CA-2 = lung cancer, CA-3 = stomach cancer, CA-4 = intestinal cancer, CA-5 = breast cancer, CA-6 = bone cancer, CA-7 = liver plus pancreatic cancer, CA-8 = cancer of urinary organs, sex organs, CA-9 = lymphoma, CA-10 = all other neoplasms not listed in CA-1 to CA-9, CAS = total of all cancers.

Table 4.6. Age-Specific Mortality Rate for the Five-Year Period 2032-2037 from Radiation-Induced Neoplasms for the Regional Population--Relative Risk Model†[1]

| Age | Population Size | Neoplasms†[2] | | | | | | | | | Other Deaths |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | CA-1 | CA-2 | CA-3 | CA-4 | CA-5 | CA-6 | CA-7 | CA-8 | CA-9 | |
| **Males** | | | | | | | | | | | |
| 5 | 2.2E+04 | 1.5E-04 | 0.0 | 0.0 | 0.0 | 0.0 | 3.1E-07 | 0.0 | 0.0 | 0.0 | 5.6E+01 |
| 10 | 2.1E+04 | 5.3E-04 | 9.4E-07 | 0.0 | 4.7E-07 | 0.0 | 4.2E-06 | 0.0 | 0.0 | 0.0 | 3.8E+01 |
| 15 | 2.2E+04 | 8.5E-04 | 7.1E-07 | 0.0 | 3.1E-06 | 0.0 | 4.1E-05 | 0.0 | 0.0 | 0.0 | 4.1E+01 |
| 20 | 1.9E+04 | 1.4E-03 | 6.6E-06 | 9.9E-06 | 2.3E-05 | 0.0 | 8.6E-05 | 1.7E-07 | 3.0E-05 | 1.1E-07 | 1.1E+02 |
| 25 | 1.9E+04 | 2.9E-03 | 1.3E-04 | 1.5E-04 | 1.5E-04 | 0.0 | 1.2E-04 | 2.1E-06 | 3.6E-04 | 1.4E-06 | 1.5E+02 |
| 30 | 1.9E+04 | 2.8E-03 | 4.6E-04 | 4.4E-04 | 4.0E-04 | 0.0 | 6.9E-05 | 7.7E-06 | 1.2E-03 | 5.1E-06 | 1.4E+02 |
| 35 | 1.9E+04 | 4.9E-03 | 3.3E-03 | 2.6E-03 | 1.7E-03 | 0.0 | 1.2E-04 | 1.3E-05 | 1.9E-03 | 8.6E-06 | 1.5E+02 |
| 40 | 1.7E+04 | 5.6E-03 | 1.5E-02 | 7.0E-03 | 4.3E-03 | 0.0 | 7.1E-05 | 9.6E-05 | 1.3E-02 | 6.4E-05 | 1.9E+02 |
| 45 | 1.5E+04 | 6.3E-03 | 6.0E-02 | 1.5E-02 | 1.3E-02 | 0.0 | 3.2E-04 | 3.3E-04 | 4.3E-02 | 2.2E-04 | 2.7E+02 |
| 50 | 1.4E+04 | 9.7E-03 | 1.1E-01 | 3.8E-02 | 2.9E-02 | 0.0 | 4.1E-04 | 6.3E-04 | 8.3E-02 | 4.2E-04 | 4.1E+02 |
| 55 | 1.6E+04 | 1.4E-02 | 2.3E-01 | 6.5E-02 | 5.8E-02 | 0.0 | 1.0E-03 | 1.4E-03 | 1.9E-01 | 9.4E-04 | 7.5E+02 |
| 60 | 1.6E+04 | 2.4E-02 | 3.5E-01 | 1.1E-01 | 9.4E-02 | 0.0 | 1.3E-03 | 2.3E-03 | 3.0E-01 | 1.5E-03 | 1.2E+03 |
| 65 | 1.4E+04 | 3.0E-02 | 3.9E-01 | 1.5E-01 | 1.1E-01 | 0.0 | 2.1E-03 | 3.2E-03 | 4.2E-01 | 2.1E-03 | 1.5E+03 |
| 70 | 1.0E+04 | 3.4E-02 | 3.4E-01 | 1.5E-01 | 1.1E-01 | 0.0 | 1.4E-03 | 3.6E-03 | 4.8E-01 | 2.4E-03 | 1.6E+03 |
| 75 | 7.2E+03 | 3.7E-02 | 2.5E-01 | 1.4E-01 | 9.7E-02 | 0.0 | 8.7E-04 | 3.7E-03 | 5.0E-01 | 2.4E-03 | 1.6E+03 |
| 80 | 4.8E+03 | 3.4E-02 | 1.5E-01 | 1.1E-01 | 7.5E-02 | 0.0 | 8.7E-04 | 3.5E-03 | 4.9E-01 | 2.3E-03 | 1.5E+03 |
| 85 | 3.2E+03 | 2.4E-02 | 7.5E-02 | 8.7E-02 | 4.9E-02 | 0.0 | 5.3E-04 | 2.7E-03 | 4.0E-01 | 1.8E-03 | 1.4E+03 |
| 90 | 2.0E+03 | 1.0E-02 | 1.6E-02 | 3.0E-02 | 1.6E-02 | 0.0 | 1.2E-04 | 1.1E-03 | 2.0E-01 | 7.4E-04 | 1.1E+03 |
| 95 | 8.9E+02 | 2.4E-03 | 4.7E-04 | 2.5E-03 | 6.2E-04 | 0.0 | 8.9E-06 | 4.2E-05 | 1.6E-02 | 3.1E-05 | 8.9E+02 |

Table 4.6. (Continued)

| Age | Population Size | Neoplasms†2 CA-1 | CA-2 | CA-3 | CA-4 | CA-5 | CA-6 | CA-7 | CA-8 | CA-9 | Other Deaths |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Females** | | | | | | | | | | | |
| 5 | 2.1E+04 | 1.0E-04 | 0.0 | 0.0 | 0.0 | 0.0 | 6.4E-07 | 0.0 | 0.0 | 0.0 | 4.3E+01 |
| 10 | 2.0E+04 | 3.7E-04 | 2.2E-07 | 0.0 | 1.8E-07 | 0.0 | 3.9E-06 | 0.0 | 0.0 | 0.0 | 2.5E+01 |
| 15 | 2.1E+04 | 4.8E-04 | 6.8E-07 | 0.0 | 8.3E-07 | 0.0 | 2.0E-05 | 0.0 | 0.0 | 0.0 | 2.2E+01 |
| 20 | 1.8E+04 | 8.2E-04 | 2.6E-06 | 0.0 | 6.1E-06 | 0.0 | 2.3E-05 | 1.5E-07 | 2.7E-05 | 1.0E-07 | 4.1E+01 |
| 25 | 1.8E+04 | 1.2E-03 | 5.6E-05 | 1.6E-04 | 6.1E-05 | 9.5E-05 | 2.8E-05 | 1.9E-06 | 3.3E-04 | 1.3E-06 | 4.9E+01 |
| 30 | 1.9E+04 | 1.5E-03 | 1.3E-04 | 3.5E-04 | 3.1E-04 | 1.2E-03 | 3.2E-05 | 6.9E-06 | 1.1E-03 | 4.6E-06 | 5.7E+01 |
| 35 | 1.9E+04 | 1.9E-03 | 7.6E-04 | 6.4E-04 | 8.7E-04 | 5.4E-03 | 3.4E-05 | 1.2E-05 | 1.7E-03 | 7.7E-06 | 7.4E+01 |
| 40 | 1.7E+04 | 3.6E-03 | 6.5E-03 | 4.4E-03 | 3.4E-03 | 1.6E-02 | 2.0E-04 | 8.5E-05 | 1.2E-02 | 5.7E-05 | 1.1E+02 |
| 45 | 1.5E+04 | 4.7E-03 | 1.6E-02 | 8.2E-03 | 8.6E-03 | 3.8E-02 | 2.9E-04 | 2.9E-04 | 3.9E-02 | 1.9E-04 | 1.4E+02 |
| 50 | 1.4E+04 | 5.7E-03 | 2.7E-02 | 1.3E-02 | 1.5E-02 | 5.5E-02 | 2.2E-04 | 5.5E-04 | 7.6E-02 | 3.7E-04 | 2.2E+02 |
| 55 | 1.6E+04 | 1.1E-02 | 4.7E-02 | 2.5E-02 | 3.2E-02 | 8.9E-02 | 3.0E-04 | 1.3E-03 | 1.8E-01 | 8.5E-04 | 3.8E+02 |
| 60 | 1.7E+04 | 1.3E-02 | 6.2E-02 | 4.1E-02 | 5.3E-02 | 1.0E-06 | 6.3E-04 | 2.1E-03 | 2.9E-01 | 1.4E-03 | 5.8E+02 |
| 65 | 1.5E+04 | 1.5E-02 | 5.6E-02 | 5.5E-02 | 6.6E-02 | 9.6E-02 | 6.6E-04 | 3.1E-03 | 4.3E-01 | 2.1E-03 | 7.6E+02 |
| 70 | 1.3E+04 | 2.0E-02 | 5.4E-02 | 6.5E-02 | 7.6E-02 | 8.9E-02 | 6.0E-04 | 4.1E-03 | 5.7E-01 | 2.7E-03 | 9.9E+02 |
| 75 | 9.6E+03 | 2.0E-02 | 4.3E-02 | 7.2E-02 | 7.3E-02 | 6.9E-02 | 9.5E-04 | 4.2E-03 | 6.1E-01 | 2.8E-03 | 1.2E+03 |
| 80 | 7.1E+03 | 1.6E-02 | 3.0E-02 | 7.2E-02 | 6.3E-02 | 5.9E-02 | 4.5E-04 | 4.4E-03 | 6.7E-01 | 3.0E-03 | 1.5E+03 |
| 85 | 5.5E+03 | 1.5E-02 | 2.1E-02 | 6.0E-02 | 4.9E-02 | 4.4E-02 | 2.7E-04 | 4.0E-03 | 6.4E-01 | 2.7E-03 | 1.8E+03 |
| 90 | 4.0E+03 | 7.1E-03 | 8.6E-03 | 3.1E-02 | 2.2E-02 | 1.9E-02 | 1.8E-04 | 2.2E-03 | 3.9E-01 | 1.5E-03 | 2.1E+03 |
| 95 | 2.0E+03 | 4.5E-03 | 3.7E-04 | 2.4E-03 | 1.1E-03 | 2.1E-03 | 1.5E-05 | 9.7E-05 | 3.7E-02 | 7.0E-05 | 2.0E+03 |

†1 Risk coefficients, delay periods, and expression periods adopted from NRC 1975 and BEIR III.

†2 CA-1 = leukemia, CA-2 = lung cancer, CA-3 = stomach cancer, CA-4 = intestinal cancer, CA-5 = breast cancer, CA-6 = bone cancer, CA-7 = liver plus pancreatic cancer, CA-8 = cancer of urinary organs, sex organs, CA-9 = lymphoma, CAS = total of all cancers.

Table 4.7. Cumulative Radiation-Induced Cancer Mortality--Absolute Risk Model

| Time (Years) | Neoplasms†[1] CA-1 | CA-2 | CA-3 | CA-4 | CA-5 | CA-6 | CA-7 | CA-8 | CA-9 | CA-10 | CAS | CAS/Death |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 10 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 6.10E-07 |
| 15 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 | 2.99E-06 |
| 20 | 0.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.3 | 8.72E-06 |
| 25 | 0.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 | 0.6 | 1.98E-05 |
| 30 | 0.9 | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.2 | 1.2 | 3.94E-05 |
| 35 | 1.6 | 0.0 | 0.1 | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.3 | 2.1 | 6.64E-05 |
| 40 | 2.5 | 0.0 | 0.2 | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.5 | 3.3 | 9.54E-05 |
| 45 | 3.5 | 0.0 | 0.2 | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.7 | 4.7 | 1.35E-04 |
| 50 | 4.7 | 0.1 | 0.3 | 0.0 | 0.2 | 0.0 | 0.0 | 0.0 | 0.0 | 1.0 | 6.3 | 1.74E-04 |
| 55 | 5.8 | 0.1 | 0.4 | 0.1 | 0.2 | 0.0 | 0.0 | 0.1 | 0.0 | 1.3 | 8.0 | 2.09E-04 |
| 60 | 6.9 | 0.1 | 0.5 | 0.1 | 0.3 | 0.0 | 0.0 | 0.1 | 0.0 | 1.6 | 9.5 | 2.36E-04 |
| 65 | 7.8 | 0.1 | 0.5 | 0.1 | 0.3 | 0.0 | 0.0 | 0.1 | 0.0 | 1.8 | 10.8 | 2.50E-04 |
| 70 | 8.6 | 0.1 | 0.6 | 0.1 | 0.4 | 0.0 | 0.0 | 0.1 | 0.0 | 2.0 | 11.9 | 2.63E-04 |
| 75 | 8.6 | 0.1 | 0.6 | 0.1 | 0.4 | 0.0 | 0.0 | 0.1 | 0.0 | 2.1 | 12.1 | 2.60E-04 |
| 80 | 8.4 | 0.1 | 0.6 | 0.1 | 0.4 | 0.0 | 0.0 | 0.1 | 0.0 | 2.1 | 11.8 | 2.52E-04 |
| 85 | 8.3 | 0.1 | 0.7 | 0.1 | 0.4 | 0.0 | 0.0 | 0.1 | 0.0 | 2.1 | 11.9 | 2.51E-04 |
| Total | 68.4 | 0.9 | 4.8 | 0.8 | 2.9 | 0.1 | 0.2 | 0.7 | 0.1 | 15.8 | 94.6 | |

†[1] CA-1 = leukemia, CA-2 = lung cancer, CA-3 = stomach cancer, CA-4 = intestinal cancer, CA-5 = breast cancer, CA-6 = bone cancer, CA-7 = liver plus pancreatic cancer, CA-8 = cancer of urinary organs, sex organs, CA-9 = lymphoma, CA-10 = all other neoplasms not listed in CA-1 to CA-9, CAS = total of all cancers, CAS/Death = ratio of cumulative spontaneous cancer mortality to all deaths.

Table 4.8. Cumulative Radiation-Induced Cancer Mortality--Relative Risk Model

| Time | Neoplasms†[1] | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| (Years) | CA-1 | CA-2 | CA-3 | CA-4 | CA-5 | CA-6 | CA-7 | CA-8 | CA-9 | CAS | CAS/Death |
| 5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 10 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 2.79E-07 |
| 15 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 | 3.57E-06 |
| 20 | 0.1 | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.2 | 0.0 | 0.4 | 1.44E-05 |
| 25 | 0.1 | 0.1 | 0.2 | 0.1 | 0.0 | 0.0 | 0.0 | 0.6 | 0.0 | 1.1 | 3.64E-05 |
| 30 | 0.1 | 0.3 | 0.3 | 0.2 | 0.1 | 0.0 | 0.0 | 1.3 | 0.0 | 2.3 | 7.28E-05 |
| 35 | 0.2 | 0.6 | 0.5 | 0.3 | 0.2 | 0.0 | 0.0 | 2.3 | 0.0 | 4.0 | 1.25E-04 |
| 40 | 0.3 | 1.0 | 0.7 | 0.5 | 0.3 | 0.0 | 0.0 | 3.5 | 0.0 | 6.3 | 1.82E-04 |
| 45 | 0.3 | 1.6 | 1.0 | 0.8 | 0.5 | 0.0 | 0.0 | 5.1 | 0.0 | 9.3 | 2.66E-04 |
| 50 | 0.4 | 2.4 | 1.3 | 1.1 | 0.7 | 0.0 | 0.0 | 7.0 | 0.0 | 13.0 | 3.57E-04 |
| 55 | 0.5 | 3.3 | 1.8 | 1.5 | 0.9 | 0.0 | 0.1 | 9.4 | 0.0 | 17.6 | 4.62E-04 |
| 60 | 0.5 | 4.4 | 2.3 | 2.0 | 1.1 | 0.0 | 0.1 | 12.4 | 0.1 | 22.9 | 5.69E-04 |
| 65 | 0.6 | 5.4 | 2.8 | 2.4 | 1.2 | 0.0 | 0.1 | 15.5 | 0.1 | 28.1 | 6.53E-04 |
| 70 | 0.6 | 6.1 | 3.1 | 2.7 | 1.2 | 0.0 | 0.1 | 17.9 | 0.1 | 31.8 | 7.05E-04 |
| 75 | 0.6 | 6.7 | 3.3 | 2.7 | 1.1 | 0.0 | 0.1 | 19.6 | 0.1 | 34.2 | 7.39E-04 |
| 80 | 0.6 | 6.9 | 3.4 | 2.8 | 1.0 | 0.0 | 0.1 | 20.6 | 0.1 | 35.5 | 7.59E-04 |
| 85 | 0.6 | 7.2 | 3.5 | 2.8 | 1.0 | 0.0 | 0.1 | 21.1 | 0.1 | 36.5 | 7.76E-04 |
| Total | 5.5 | 46.0 | 24.1 | 20.0 | 9.3 | 0.2 | 0.8 | 136.7 | 0.6 | 243.2 | |

†[1] CA-1 = leukemia, CA-2 = lung cancer, CA-3 = stomach cancer, CA-4 = intestinal cancer, CA-5 = breast cancer, CA-6 = bone cancer, CA-7 = liver plus pancreatic cancer, CA-8 = cancer of urinary organs, sex organs, CA-9 = lymphoma, CAS = total of all cancers, CAS/Death = ratio of cumulative spontaneous cancer mortality to all deaths.

during the five-year period 1982-1987 is predicted to be 31,954 (Table 4.9), resulting in 684 genetic disorders per year from natural causes. The total number of genetic disorders induced by exposure to the radiation from the mines during the same five-year period is predicted to be 0.1 for each type of genetic disorder. The estimated ratio of radiation-induced to naturally induced genetic disorders is about $3 \times 10^{-4}$.

Under Alternatives B through D, risks of somatic (except for cancer of the lung) and genetic effects would be reduced to less than 0.1% of those levels calculated above for Alternative A. The risk of lung cancer would decrease to about 25% and 10% of the risks under Alternative A for Alternatives B and C1 through D, respectively.

## 4.5 DISCUSSION OF HEALTH EFFECTS

Potential mortalitiy from natural causes and from present conditions of radiation exposure in the vicinity of the Jackpile-Paguate mines was calculated for a 90-year period using both absolute and relative radiation-risk models. The changes in the population size, birth rates, and radiation-induced and natural mortality are summarized in Table 4.9. Under the existing radiation environment at the mines, about 243 radiation-induced deaths from nine types of neoplasms were projected to occur under the relative risk model, compared to about 95 deaths from all neoplasms under the absolute risk model (Table 4.9). It is anticipated that after decommissioning of the mine site, both somatic and genetic effects would decrease to about 0.1% of the predicted potential risks for all organs except for the respiratory system. Because of the contribution of radon decay products, the risk of lung cancer could decrease to about 4% of the prereclamation values.

Since the relative risk model includes consideration of the spontaneous incidence of diseases, the predictions are affected by the data base selected. The spontaneous incidence of some neoplasms is different among the races and even among racially similar populations in different regions. Because of this, use of the relative risk model could result in predictions of dissimilar risks from the same exposure. In contrast, the absolute risk model would yield the same estimate of additional deaths for the same exposure, and it would be independent of the year selected for analysis.

Among the many input parameters used in analysis of risk are risk coefficients, delay period, and period of expression of the risk. The bounds of uncertainty in these parameters, which depend on age, sex, race, and rate and duration of exposure (Momeni et al. 1976), are not known. Probability of incidence of radiation-induced diseases is a continuous function (Goffman 1981; Momeni 1979), often expressed as a step function with fixed duration of expression and delay (NAS 1972; USNRC 1975). For these analyses, variable expression periods with age-dependent incidence rates were utilized where the data were available. Expression of the probability function as lognormal or normal function is facilitated in the PRIM code, but was not used for these analyses. The shape of the probability density function does not seem to be unique (Momeni 1979) and is dependent on the pattern of exposure, as well as on age.

A crucial problem in analysis of risk is assignment of confidence limits. To quantify the uncertainties in the results, the uncertainties of the values of the parameters used in the calculations must be propogated through the analysis.

Table 4.9. Population Characteristics and Cumulative Natural and Potential Radiation-Induced Mortality for Period 1982-2072

| Time (Years) | Total Population | Total Births | Natural Cancer Deaths | Radiation-Induced Cancer Deaths | All Deaths |
|---|---|---|---|---|---|
| Absolute Risk Model | | | | | |
| 5 | 362,100 | 31,954 | 4,564.9 | 0.0 | 22,079.5 |
| 10 | 371,974 | 36,283 | 5,044.3 | 0.0 | 23,752.0 |
| 15 | 384,505 | 39,392 | 5,514.8 | 0.1 | 26,738.8 |
| 20 | 397,158 | 39,798 | 5,923.7 | 0.3 | 29,149.7 |
| 25 | 407,807 | 38,410 | 6,282.0 | 0.6 | 30,517.0 |
| 30 | 415,700 | 38,034 | 6,610.2 | 1.2 | 31,170.6 |
| 35 | 422,564 | 43,704 | 6,934.9 | 2.1 | 31,999.1 |
| 40 | 434,269 | 42,170 | 7,287.1 | 3.3 | 34,700.3 |
| 45 | 441,739 | 43,766 | 7,695.2 | 4.7 | 35,024.6 |
| 50 | 450,480 | 44,162 | 8,202.0 | 6.3 | 36,480.6 |
| 55 | 458,162 | 44,991 | 8,817.5 | 8.0 | 38,056.4 |
| 60 | 465,097 | 46,570 | 9,462.4 | 9.5 | 40,379.6 |
| 65 | 471,287 | 47,962 | 10,001.1 | 10.8 | 43,065.1 |
| 70 | 476,183 | 49,013 | 10,343.5 | 11.9 | 45,194.7 |
| 75 | 480,001 | 49,973 | 10,503.7 | 12.1 | 46,367.1 |
| 80 | 483,607 | 50,957 | 10,604.9 | 11.8 | 46,865.6 |
| 85 | 487,699 | 52,231 | 10,799.6 | 11.9 | 47,177.8 |
| Relative Risk Model | | | | | |
| 5 | 362,100 | 31,954 | 4,564.9 | 0.0 | 22,079.5 |
| 10 | 371,974 | 36,283 | 5,044.3 | 0.0 | 23,752.0 |
| 15 | 384,505 | 39,392 | 5,514.8 | 0.1 | 26,738.9 |
| 20 | 397,158 | 39,798 | 5,923.7 | 0.4 | 29,149.8 |
| 25 | 407,807 | 38,410 | 6,282.0 | 1.1 | 30,517.4 |
| 30 | 415,700 | 38,034 | 6,610.1 | 2.3 | 31,170.8 |
| 35 | 422,562 | 43,702 | 6,934.6 | 4.0 | 31,999.0 |
| 40 | 434,265 | 42,166 | 7,286.4 | 6.3 | 34,699.2 |
| 45 | 441,732 | 43,758 | 7,694.0 | 9.3 | 35,021.7 |
| 50 | 450,468 | 44,149 | 8,199.7 | 13.0 | 36,474.4 |
| 55 | 458,143 | 44,969 | 8,813.5 | 17.6 | 38,043.9 |
| 60 | 465,067 | 46,535 | 9,455.9 | 22.9 | 40,359.9 |
| 65 | 471,242 | 47,908 | 9,991.1 | 28.1 | 43,032.1 |
| 70 | 476,117 | 48,936 | 10,329.1 | 31.8 | 45,142.8 |
| 75 | 479,911 | 49,868 | 10,485.0 | 34.2 | 46,294.4 |
| 80 | 483,484 | 50,820 | 10,582.4 | 35.5 | 46,772.1 |
| 85 | 487,531 | 52,059 | 10,773.0 | 36.5 | 47,061.3 |

A rigorous error analysis is often not feasible because of limited knowledge concerning the confidence limits of the input parameters, subjective selection of a value for some of the risk coefficients, and numerical validity of models utilized in prediction of radiation doses and assessment of risks. Furthermore, use of conservative values for the input parameters, whenever the actual values are not known, would result in larger predictions than expected. Even though selection of overly conservative values for these analyses was avoided to the extent possible, values for some the input parameters were unavailable, so there is an element of uncertainty concerning the calculated doses. The magnitude of uncertainty in doses is surmised to be not less than a factor of five (± 2.5 times) for some organs and at some localities. Similarly, the uncertainty in the risks is surmised to be not less than a factor of 5 (± 2.5 times) of the risks predicted here.

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# 5. ANALYSIS OF HYDROLOGIC FLOW PATTERNS

## 5.1 INTRODUCTION

Hydrologic flow patterns in the mine area were analyzed to determine the potential for future contamination of the surface and groundwater, and thus permit incorporation of corrective actions in the reclamation procedures. The technique of hydrological simulation was used to predict potential groundwater flow, transport of radionuclides, and equilibrium groundwater level after decommissioning of the Jackpile-Paguate mines. Because of the limited amount of data available on groundwater in the area, and the fact that the natural geologic stratification of the mine site has been altered by past mining operations, simplified assumptions were used to model the groundwater flow. The assumptions are detailed and input parameters listed in Appendix C.

The analysis of flow pattern includes consideration of the following factors: (1) pattern of rainfall infiltration through waste piles into groundwater, (2) pattern of infiltration of ponded water behind blocked arroyos and in mine pits into groundwater, and (3) ponding of groundwater in the mine pits. These analyses may provide information on (1) equilibrium level of groundwater after reclamation, (2) extent of contact between equilibrium level of groundwater and the mine wastes, (3) depth of soil cover required in the mine pits to eliminate surface ponding of the groundwater, and (4) discharge flow pattern of groundwater into Rio Paguate and Rio Moquino.

## 5.2 INFILTRATION OF PRECIPITATION AND SURFACE WATER INTO GROUNDWATER

The potential for contamination of groundwater by infiltration of rainfall or ponded water containing radionuclides from the waste piles was studied by cross-sectional flow analysis. In this simulation, a waste pile of dimensions equivalent to the "S" pile (Fig. 2.24) was assumed to be adjacent to the blocked arroyo. A pond was assumed to be formed by runoff behind the dammed arroyo. The pond was further assumed to have a maximum head of 0.6 m (2 ft) of water during rainfall, but disappearing shortly after rainfall. The cross section of the waste pile and the pond are shown along with information on pertinent hydrologic characteristics in Figure 5.1.

Three scenarios of intermittent effective rainfall [rainfall of 5 cm/month (2 in/month) minus infiltration of 2.5 cm/month (1 in/month)] averaging 2.5 cm/month (1 in/month) were considered (Fig. 5.2). In the first case, it was assumed that a 90-day period of continuous rainfall was followed by a 180-day dry season, then by 90 more days of continuous rainfall. This would be an upper-limit case resulting in a high rainfall-infiltration pattern. For the second case, the pattern was changed to a cycle of 30 days of continuous rainfall, followed by a dry season lasting 150 days. In the third case, a period of continuous rainfall of only 10 days was assumed. Conditions around the Jackpile-Paguate mines are more typical of this third case.

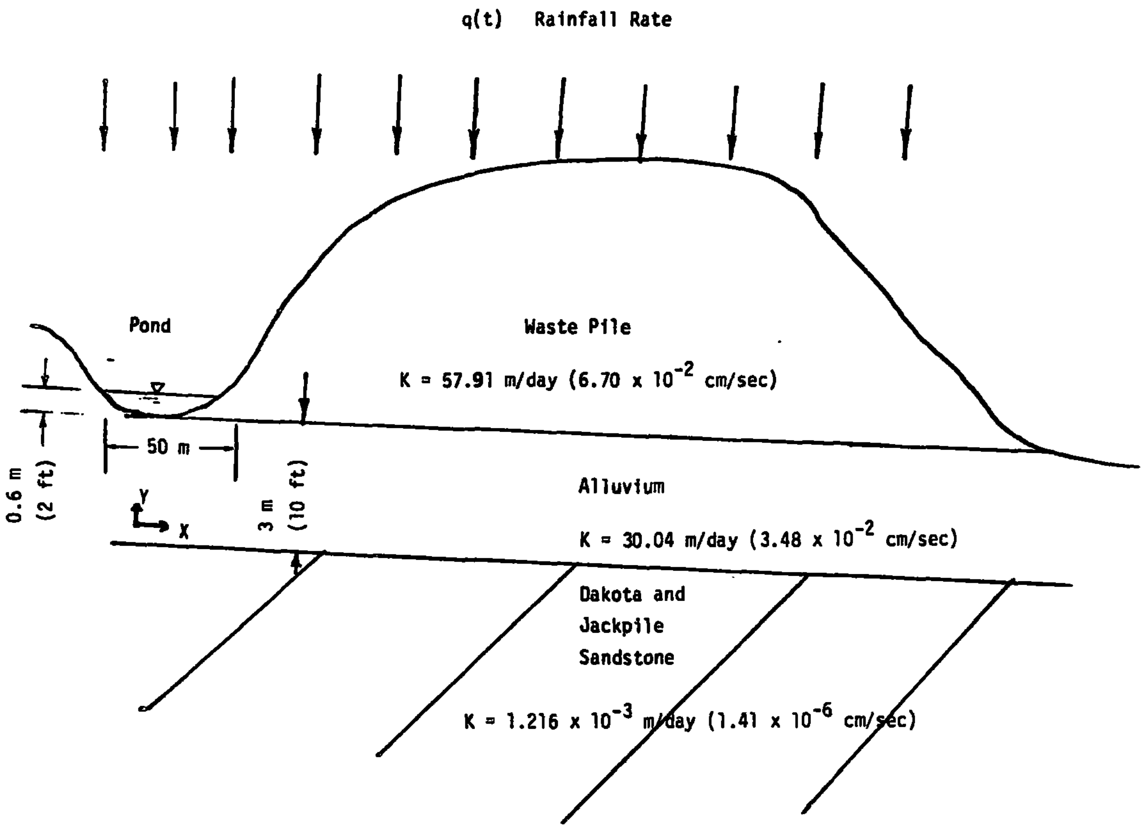
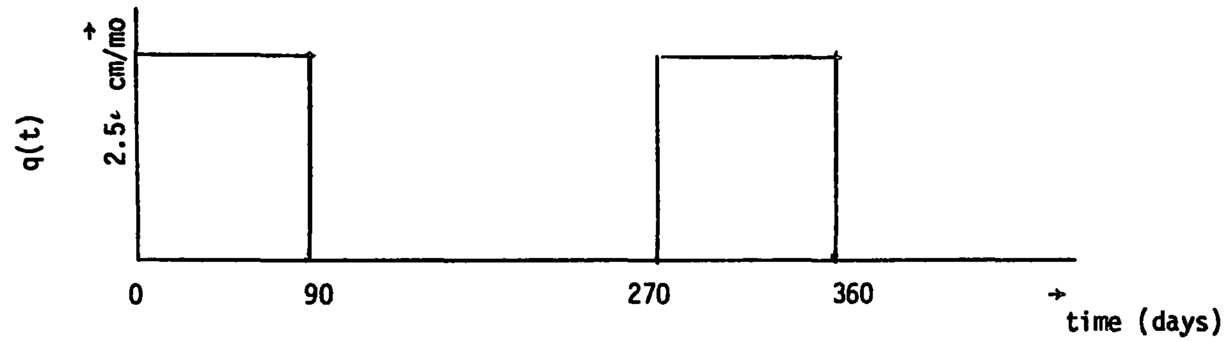


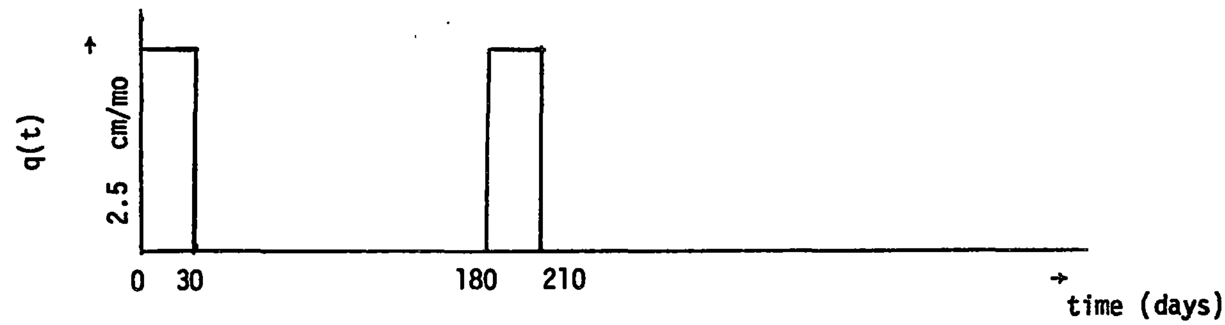

Figure 5.1. Schematic Diagram of the Wastepile and Ponded Water behind the Blocked Arroyo.

Water-table fluctuations were simulated over a period of one year for each of the three rainfall patterns. The method used to compute the resulting groundwater mounds and graphical results of each flow pattern are presented in Appendix C. The cross sections of the groundwater mound beneath the pond formed by rain runoff are shown in Figures 5.3 through 5.5 for the rainfall patterns of cases 1, 2, and 3, respectively. The x axis on the figures is distance in the horizontal direction, and x = 0 is located at the geometric center of the pond. The "y" axis is the height of the groundwater mound above the interface between the alluvium and the bedrock (Dakota and Jackpile sandstone). The time periods indicated are from the beginning of the rainfall. The groundwater mound is assumed to be symmetrical, and the flow patterns are identical in all directions from the x-axis. More detailed analyses, results, and discussions are included in Section C.3, Appendix C.

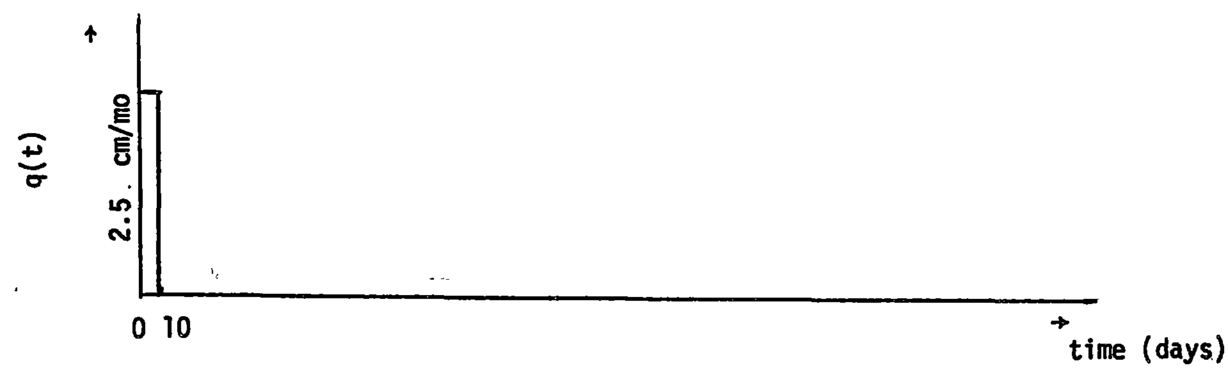
The analyses indicated that in all cases the groundwater would spread horizontally without directly contacting the waste piles. It also was indicated that the potential for contamination of groundwater with radionuclides from the waste piles as a result of infiltration of rainfall or pond recharge would be minimal.




Case 1




Case 2




Case 3

**Figure 5.2. Three Cases of Intermittent Rainfall.**

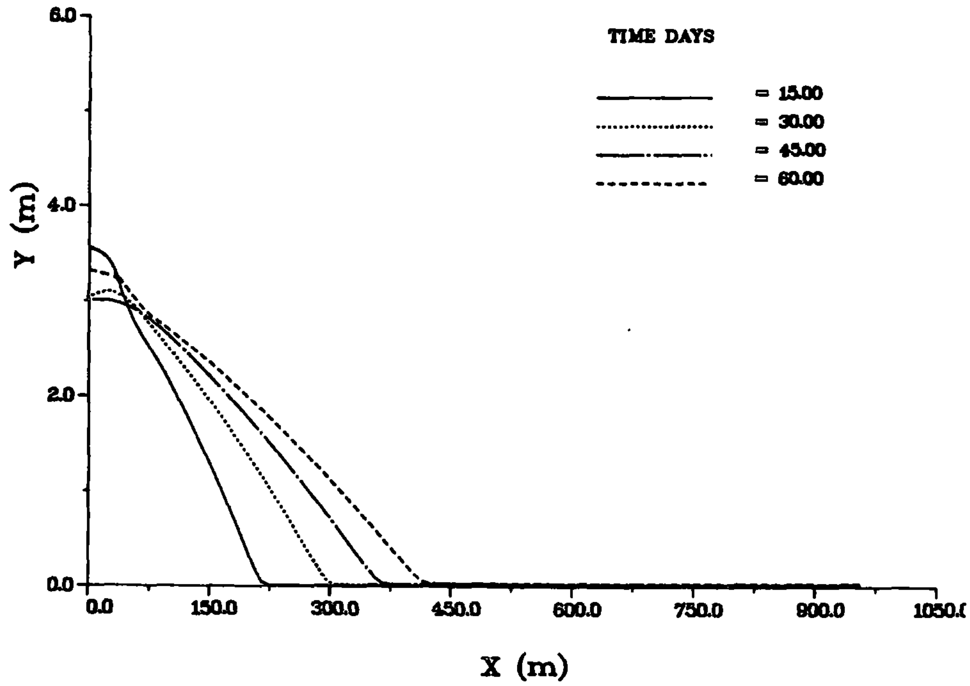



Figure 5.3. Calculated Cross Sections of Groundwater Mound under Case 1 Rainfall Pattern--Days 15-60.

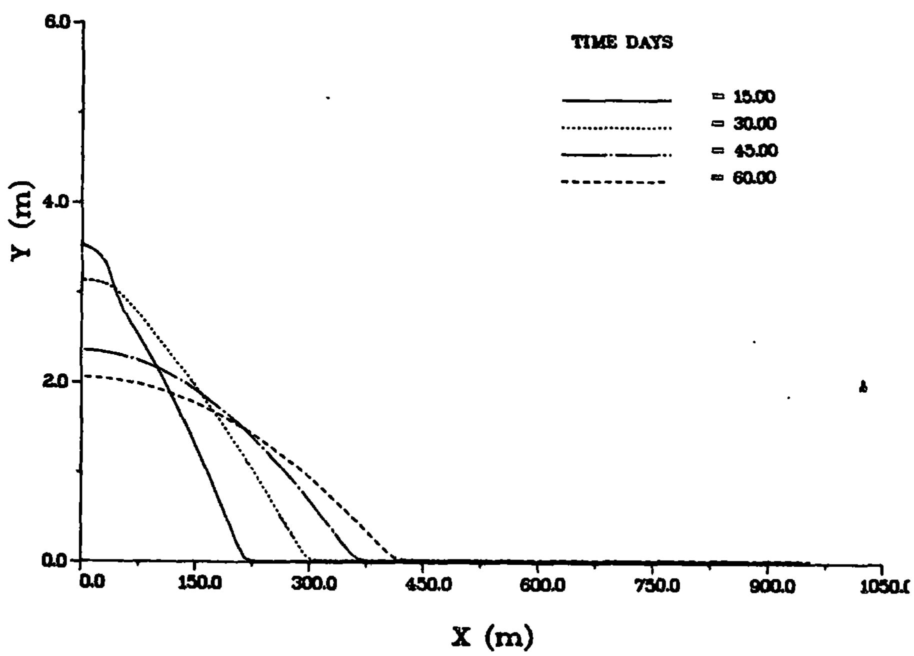



Figure 5.4. Calculated Cross Sections of Groundwater Mound under Case 2 Rainfall Pattern--Days 15-60.

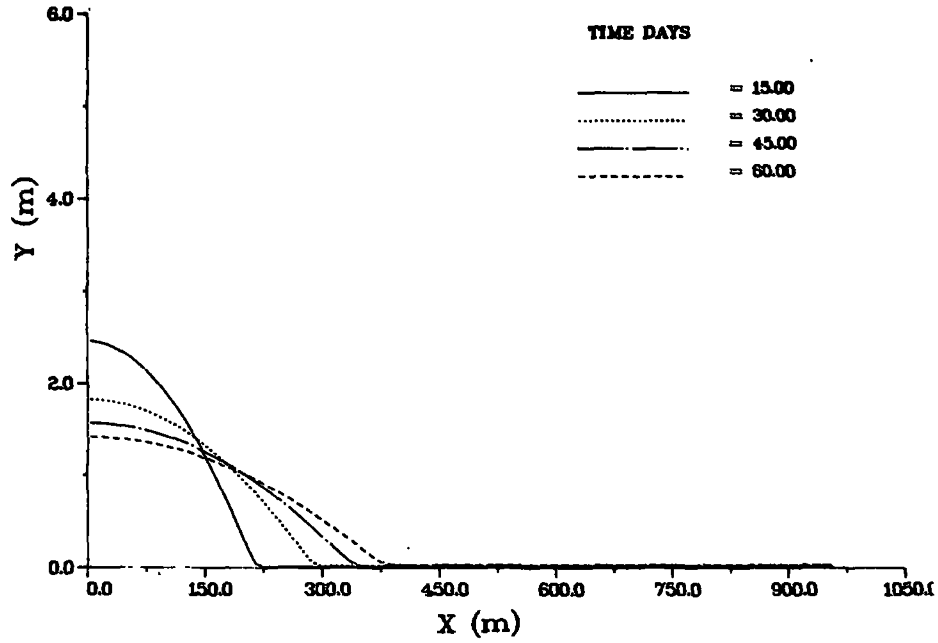



Figure 5.5. Calculated Cross Sections of Groundwater Mound under Case 3 Rainfall Pattern--Days 15-60.

## 5.3 INFILTRATION OF PRECIPITATION INTO WASTE PILES

The methods used to analyze infiltration of precipitation into waste piles are similar to those outlined in Section 5.2, the major difference being that the presence of ponded water was not incorporated into this model. The analysis indicates that the infiltration of rainfall through a waste pile would not cause further degradation of groundwater quality. This is because moisture in the ground would evaporate before formation of a saturated zone above the interface of alluvium and the bedrock.

## 5.4 SURFACE PONDING OF GROUNDWATER

Ponded groundwater in the open mine pits contains elevated concentrations of radionuclides and toxic chemicals similar to those in the groundwater under the site (see Sec. 2.3.2.3). Both the Anaconda Co. and the U.S. Department of the Interior Task Force proposals for mine reclamation include provisions to backfill the mine pits to above the equilibrium groundwater recovery level and eliminate surface ponding of groundwater. Detailed calculations of equilibrium groundwater recovery level are presented in the following sections.

### 5.4.1 Anaconda Proposal

The Anaconda proposal for reclamation (Alternative C1) provides for all open pits to be backfilled to 1 m (3 ft) above the groundwater recovery level. This might result in the elimination of the potential for surface ponding of groundwater after the recovery of the aquifer. Because the backfill material might be about two or three orders of magnitude more permeable than the original undisturbed Jackpile sandstone it replaces (Hydro-Search 1981), the post-mining equilibrium water recovery levels in the mine area might be lower than the pre-mining potentiometric surface. After reclamation, most of the groundwater would move through the ground and backfilled open-pit mines toward the Rio Paguate. Additionally, some water might continue to move through the surrounding and underlying undisturbed Jackpile sandstone. Most of the water in the Jackpile pit backfill would move through the surrounding Jackpile sandstone and eventually enter the alluvium and the Rio Paguate. The water in the backfill in the Paguate pits would discharge principally into that reach of the Rio Paguate adjacent to the pits. More detailed analysis of groundwater flow in backfill in the Paguate pits after reclamation is provided in Section 5.5. Because the Rio Paguate is the discharge point for the groundwater, the water level in the stream will also control the total amount of water discharged from the pits.

### 5.4.2 Department of the Interior Proposal

Department of the Interior Task Force proposal for reclamation (Alternative C2) provides for all open pits to be backfilled to 3 m (10 ft) above the groundwater recovery level. The hydrological conditions described above for the Anaconda proposal also may prevail under this proposal, except that the possibility of groundwater ponding is less likely under the Department of the Interior proposal.

## 5.5 PREDICTION OF EQUILIBRIUM GROUNDWATER LEVEL IN SOUTH PAGUATE PIT

An analysis was conducted to determine the equilibrium groundwater level in the South Paguate pit after it has been backfilled. This was done to calculate the level of backfill needed to preclude surface ponding of groundwater in the pit following recovery of the aquifer.

The Rio Paguate separates the South Paguate pit from the North Paguate pit (Fig 5.6). The two pits were connected by an excavation across and beneath the Rio Paguate. Prior to mining of the Paguate pit area, the Rio Paguate was rechanneled for about 600 m (2000 ft) from the point where it entered the western edge of the mine lease just south of the town of Paguate (Fig. 5.6) (Hydro-Search 1981). The rechanneled streambed was lined with backfill material. The backfill beneath the streambed extends from the stream to the central part of the South Paguate pit, providing a potential drain for groundwater leaving the pit. To determine the equilibrium groundwater levels that will be established after reclamation of the South Paguate pit, a flow section representing the most likely path for groundwater flow in the area was chosen. This section, as indicated in Figure 5.6, stretches from the southernmost edge of the pit (southeast of well P6) to the Rio Paguate upstream from well P4. A schematic diagram showing the cross section of the selected flow path is presented in Figure 5.7.

The backfill beneath the Rio Paguate is of variable thickness. A cross section prepared by Anaconda Co. (cross section 12 of "Jackpile-Paguate Mine Additional Cross Sections 1-19," undated) shows backfill under the stream to be 12 m (40 ft) deep. Well site P4 is underlain by about 5 m (16 ft) of fill (Hydro-Search 1979). The length of stream channel exposed to fill from the South

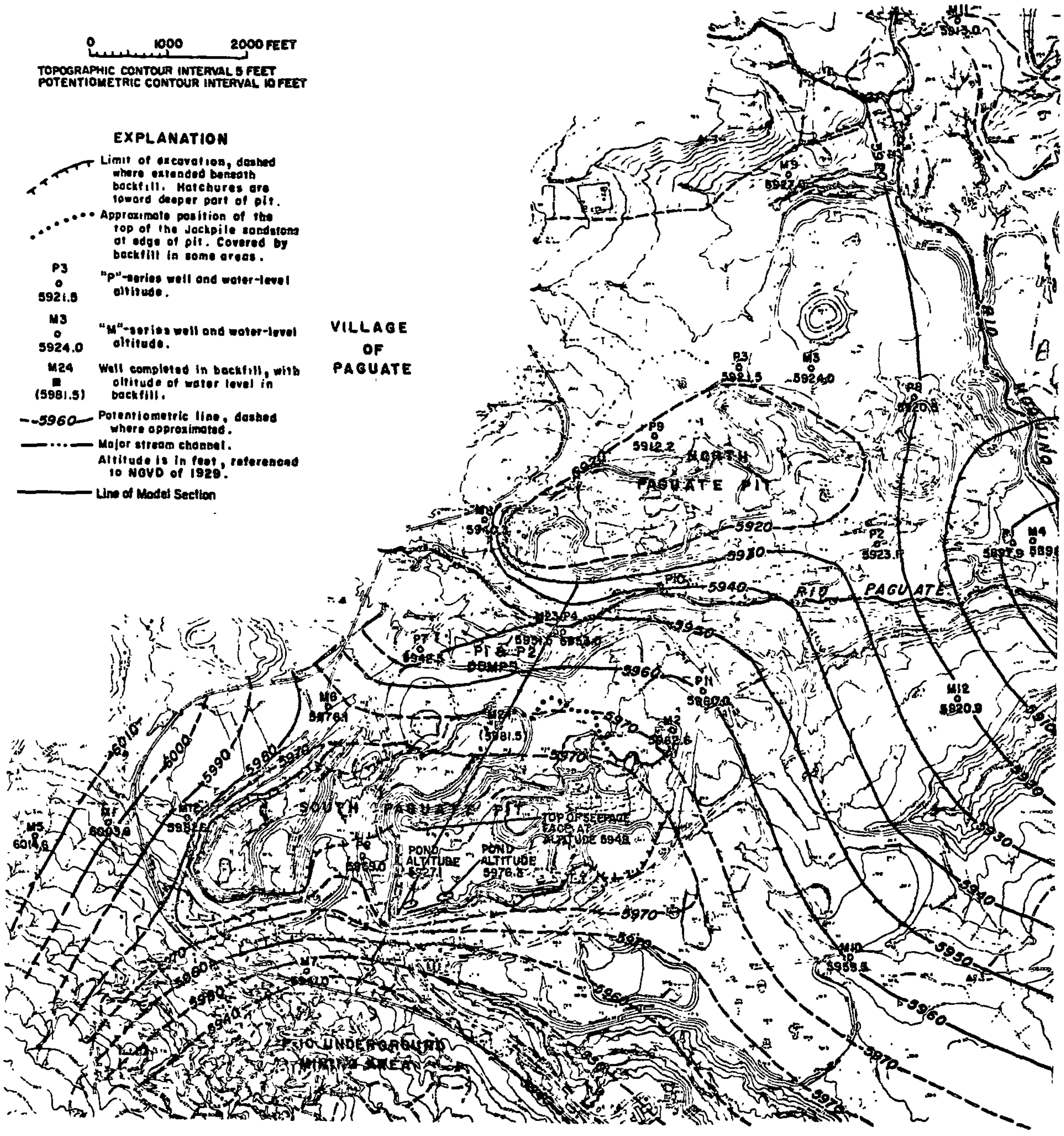



Figure 5.6. Topographic and Hydrologic Map of the South Paguate Pit Area.

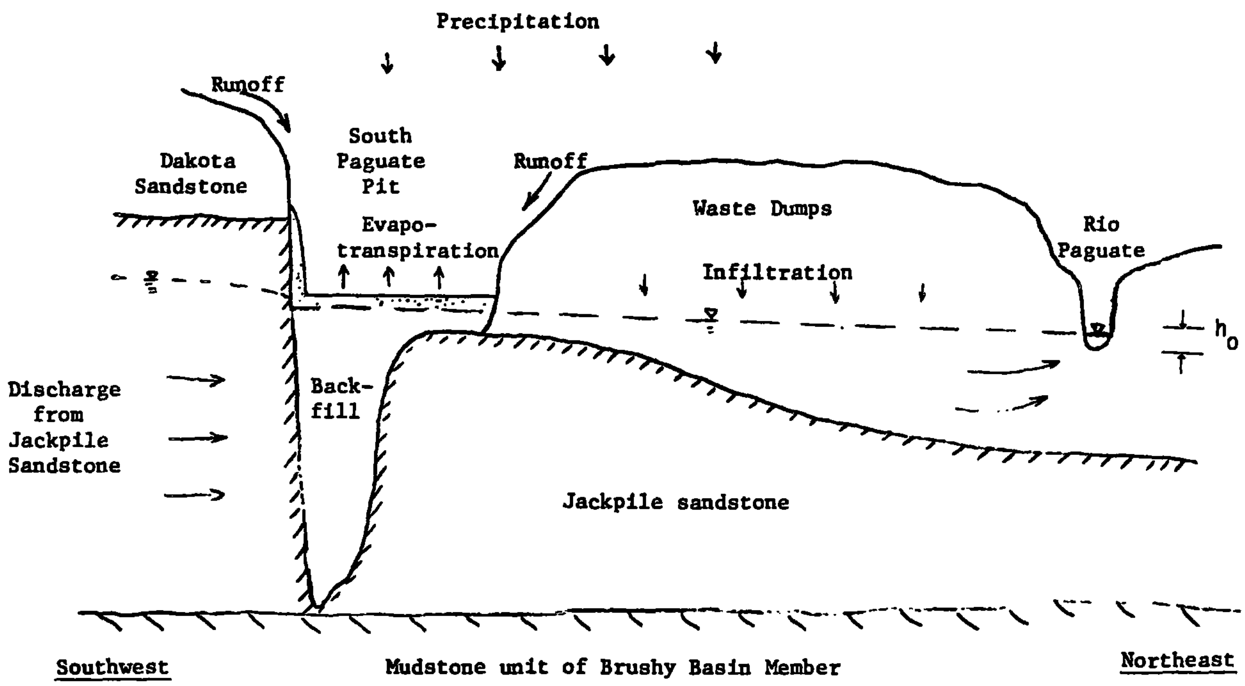



Figure 5.7. Schematic Diagram Showing the Cross Section of Selected Groundwater Flow Path through the South Paguate Pit.

Paguate pit is about 490 m (1600 ft), as measured between the upstream and downstream ends of the pit.

The existing waste dump, as shown in Figure 5.7, overlies the Jackpile sandstone, which is underlain by a mudstone unit of the Brushy Basin member. The sandstone is both the ore-bearing formation and the principal bedrock aquifer in the area. The mudstone unit is assumed to be the lower hydrologic boundary in the local groundwater system. Most recharge in the Jackpile-Paguate pit area probably occurs at the higher altitudes north of the mine, where there is likely to be more rainfall and less evaporation. Waterhead data from wells indicate that in the South Paguate pit area, groundwater in the Jackpile sandstone generally moves to the northeast. Seepage occurs at open-pit faces where saturated Jackpile sandstone has been excavated. Since the bottom of the Jackpile sandstone is near the bottom of the pit (Fig 5.7), flow in the sandstone is almost completely intercepted along the western and southern peripheries of the pit for a distance of about 2400 m (8000 ft) (Fig. 5.6).

The water now discharging into the pit usually evaporates at the seepage surface, or collects in the pit and is later used for dust suppression. After the South Paguate pit is backfilled, the seepage into the pit will tend to saturate the pit backfill and then flow primarily through backfill material to the Rio Paguate. There will be very little leakage into the underlying Jackpile sandstone. The positions representing the top of the Jackpile sandstone in Figure 5.7 were sketched on the basis of Anaconda Co. exploration hole data and lithologic descriptions of wells (Hydro-Search 1980, 1981). It is indicated in the diagram that the gradient of the Jackpile sandstone surface is about half a degree from the pit to the stream.

The position of the water table at equilibrium in the South Paguate pit area was estimated by using the Dupuit formula derived for two-dimensional unconfined flow (Harr 1962, Polubarinova-Kochima 1962). Detailed descriptions of the formula can be found in the references cited and in Appendix C.4. The parameters required to calculate the groundwater level, the corresponding symbols used in the Dupuit formula, and the values selected for the parameters are shown in Table 5.1. The reasons for these selections are discussed in Appendix C.4. The computations of equilibrium groundwater levels were made by first determining the amount of recharge into the pit, which includes the discharge from the Jackpile sandstone and local infiltration from direct precipitation and runoff. The bedrock discharge into the pit [about 0.33 $m^3$/day per meter (3.6 $ft^3$/day per foot) of stream length] was calculated from the Darcy's equation with the hydraulic gradient ($I_j$) in the Jackpile sandstone taken from the value measured at wells M1 and M5 (Fig. 5.6). The amount of infiltration was assumed to be 0%, 5%, and 10% of local precipitation.

After determining the recharge and assuming the controlling flow depth ($h_o$) in the Rio Paguate, the positions of the water table in the South Paguate pit area were back-calculated from $h_o$.

Table 5.1. Selected Data for Groundwater Flow Analysis for South Paguate Pit

| Symbol | Parameter | Values †[1] |
|---|---|---|
| P | Annual average precipitation | 9.5 in |
| A | Drainage area for South Paguate pit | 400 ac |
| $h_o$ | Flow depth in Rio Paguate | 0, 2, 5 ft |
| $K_j$ | Hydraulic conductivity of Jackpile sandstone | 0.3 ft/day |
| $K_b$ | Hydraulic conductivity of backfill material | 190 ft/day |
| $I_j$ | Equilibrium hydraulic gradient in Jackpile sandstone | 0.02 |
| $B_j$ | Saturated thickness of Jackpile sandstone | 120 ft. |
| $\alpha$ | Angle of inclination of sandstone surface | $0^\circ \sim 42^\circ$ |
| L | Horizontal distance between the pit and Rio Paguate | 5,500 ft |

†[1]Conversions: 1 in = 2.54 cm; 1 ft = 0.3048 m; 1 ac = 4.046 x $10^3$ $m^2$.

Results of the computations, showing the differences ($\Delta h$) between the water level in backfill at the southern end of the pit and the streambed level, are presented in Table 5.2. For the maximum discharge conditions considered in this study, the maximum $\Delta h$ would be about 3 m (9 ft). The results also indicate that a sloping bedrock surface would not result in an appreciable change in the groundwater level. For the same flow conditions, the maximum difference would be only about 0.2 m (0.7 ft). The reason for this small difference is that the transmissivity of the backfill is so great that it dominates the flow characteristics. The elevation of backfill needed in the South Paguate pit can be determined on the basis of the $\Delta h$ values shown in Table 5.2. Hydro-Search Inc. (1979, 1981) indicated that the stream-level elevation (above mean sea level) at well M23 is 1829 m (6000 ft), and about 300 m (1000 ft) downstream from well M23 it is 1821 m (5975 ft). The maximum elevation of the water level at the southern end of the pit would, therefore, be between 1832 and 1824 m (6009 and 5984 ft). At the northern end of this pit, which is about 910 m (3000 ft) from Rio Paguate, the maximum $\Delta h$ wuld be about 2 m (7 ft). The maximum water level at this location would be between 1831 and 1823 m (6007 and 5982 ft) above mean sea level. Elevations of the equilibrium water level inside the South Paguate pit would, therefore, vary from 1832 to 1823 m 6009 to 5982 ft).

## 5.6 PREDICTION OF EQUILIBRIUM GROUNDWATER LEVEL IN JACKPILE PIT

The procedures used to determine the equilibrium groundwater level in the Jackpile pit were basically the same as those described in the previous section for the South Paguate pit. However, the hydrogeologic characteristics of these two areas are somewhat different.

The Jackpile pit is east of Rio Moquino and Rio Paguate and west of Gavilan mesa. The mesa, with a maximum elevation of 1967 m (6453 ft), is the highest area around the Jackpile pit. A topographic/hydrologic map of the vicinity of the pit is presented in Figure 5.8.

Several wells were installed in 1977 and 1980 to conduct hydrologic studies in the Jackpile-Paguate mining area. Locations of those wells surrounding Jackpile pit are shown in Figure 5.8. Most of the wells are open to the Jackpile sandstone, the principal aquifer in the area. None are completed solely in bedrock overlying the Jackpile sandstone. Well M17, which is at the south-western end of the Jackpile pit, was drilled into mine waste rock.

Wells drilled to the Jackpile sandstone are generally open to the entire thickness of the stratum, and therefore can be used to determine general directions of groundwater flow and general groundwater gradients in that stratum. Groundwater data from selected test wells indicate that recharge flow into the Jackpile mine area is probably from overlying strata to the north. There is no apparent recharge area to the east of the Jackpile pit. It can be surmised that flow from that direction is the local recharge through the fractured rocks in Gavilan mesa. Data supporting this assumption are not available.

The waste dump at the southwestern end of the Jackpile pit extends southward to a small mesa on which well M18 is located. Although there are insufficient data to clearly determie the flow direction in the vicinity of well M18, it is presumably toward the Rio Paguate.

Table 5.2. Equilibrium Groundwater Levels in South Paguate Pit for Both Horizontal and Inclined Bedrock Surfaces†[1]

| Bedrock Discharge into Backfill ($q_i$) ($ft^3$/day/ft) | Rate of Infiltration into Backfill ($q_i$) ($ft^3$/day/ft) | Total Discharge in Backfill (q) ($ft^3$/day/ft) | Assumed River Flow Depth (ft) | Water Level above Streambed ($\Delta h$) (ft) | |
|---|---|---|---|---|---|
| | | | | $\alpha = 0$†[2] | $\alpha \neq 0$†[2] |
| 3.6 | 0 | 3.6 | 0 | 2.5 | 2.4 |
| | | | 2 | 4.4 | 4.2 |
| | | | 5 | 7.3 | 7.2 |
| 3.6 | 1.2 | 4.8 | 0 | 3.3 | 3.0 |
| | | | 2 | 5.2 | 4.9 |
| | | | 5 | 8.0 | 7.6 |
| 3.6 | 2.4 | 6.0 | 0 | 4.1 | 3.6 |
| | | | 2 | 6.0 | 5.4 |
| | | | 5 | 8.7 | 8.0 |

†[1] Conversion: 1 ft = 0.3048 m.

†[2] $\alpha$ = angle of inclination of sandstone surface.

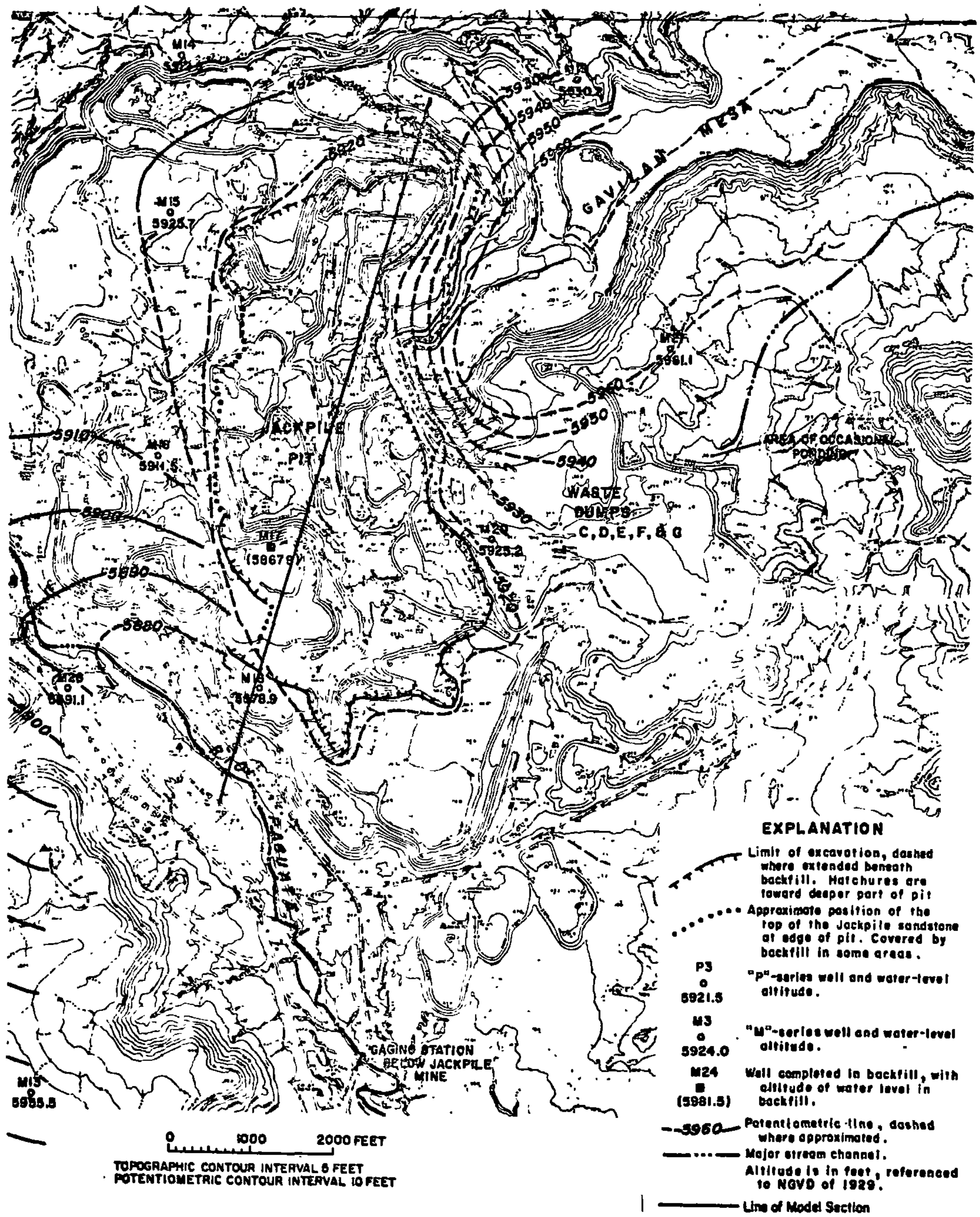



Figure 5.8. Topographic and Hydrologic Map of the Jackpile Pit Area.

To determine the equilibrium groundwater levels in the Jackpile pit after reclamation, a flow section representing the most likely flow path for groundwater in the area was chosen. This section, as indicated in Figure 5.8, stretches from the western edge of Gavilan Mesa, through the site of well M18, to the Rio Paguate. A conceptual diagram showing the geologic cross section along the selected flow path is presented in Figure 5.9. The relative positions of the surface of the existing backfill and the bedrock surface beneath the backfill were approximated on the basis of cross-sectional data provided by the Anaconda Co.

Mancos shale above the Dakota sandstone forms the tops of the locally high mesas. The existing backfill overlies the Jackpile sandstone, which in turn is underlain by the mudstone unit of the Brushy Basin member. The mudstone, which is composed of fine sand to silt-sized fragments, is assumed to be the lower hydrologic boundary in the local groundwater system. As previously mentioned, recharge in the area occurs mostly at the higher elevations north of the mine. Sources of water entering the Jackpile pit are the same as for South and North Paguate pits, i.e., the discharge from the Jackpile sandstone and local infiltration from direct precipitation and runoff. Discharge from Jackpile pit backfill would be through the Jackpile sandstone, and most of the water would probably enter the alluvium and the Rio Paguate southwest of the pit. The level of the Rio Paguate would therefore be the ultimate hydraulic control for water levels in backfill at the Jackpile pit. Discharge at the southern end of the Jackpile pit could also be through the mudstone unit of the Brushy Basin member. However, since an areal model of groundwater flow is not readily available, and since the mudstone stratum is relatively impermeable compared to the Jackpile sandstone and the waste fill, the groundwater in the Jackpile pit area was assumed to flow in the direction of the path shown in Figure 5.8.

Groundwater discharge in the Jackpile pit area would flow across at least four boundaries of different strata, compared with only two boundaries in the Paguate pits. After reclamation, groundwater levels in backfill would move toward equilibrium between potential heads in Gavilan mesa and the levels of the streams adjacent to the pit. The Rio Moquino is at an elevation of 1806 m (5925 ft) west of the Jackpile pit, and the Rio Paguate is at an elevation of about 1785 m (5855 ft) near the southwestern end of the pit.

Because field data for such parameters as exact positions of the saturated zones, the hydraulic gradients, and the hydraulic conductivity of rocks other than the Jackpile sandstone were lacking, use of sophisticated numerical models to determine the equilibrium groundwater level in the Jackpile pit area was not warranted. Instead, the water level was estimated by developing a computer program based on the Dupuit formula for two-dimensional unconfined flow (Polubarinova-Kochima 1962; Harr 1962). The parameters required for the Dupuit formula and the values selected are shown in Table 5.3. The discharge from Jackpile sandstone into the backfill was estimated by assuming an equilibrium hydraulic gradient ($I_j$) for the sandstone. This assumed gradient was later compared with the calculated groundwater level. If the calculated gradient was significantly different from the assumed value, the average of the two values was taken as the new gradient and the calculation of groundwater level was repeated. Using this trial and error process, the final solutions were obtained when the assumed and the calculated hydraulic gradients for the recharge area were in close agreement. The discharge to the Jackpile pit from

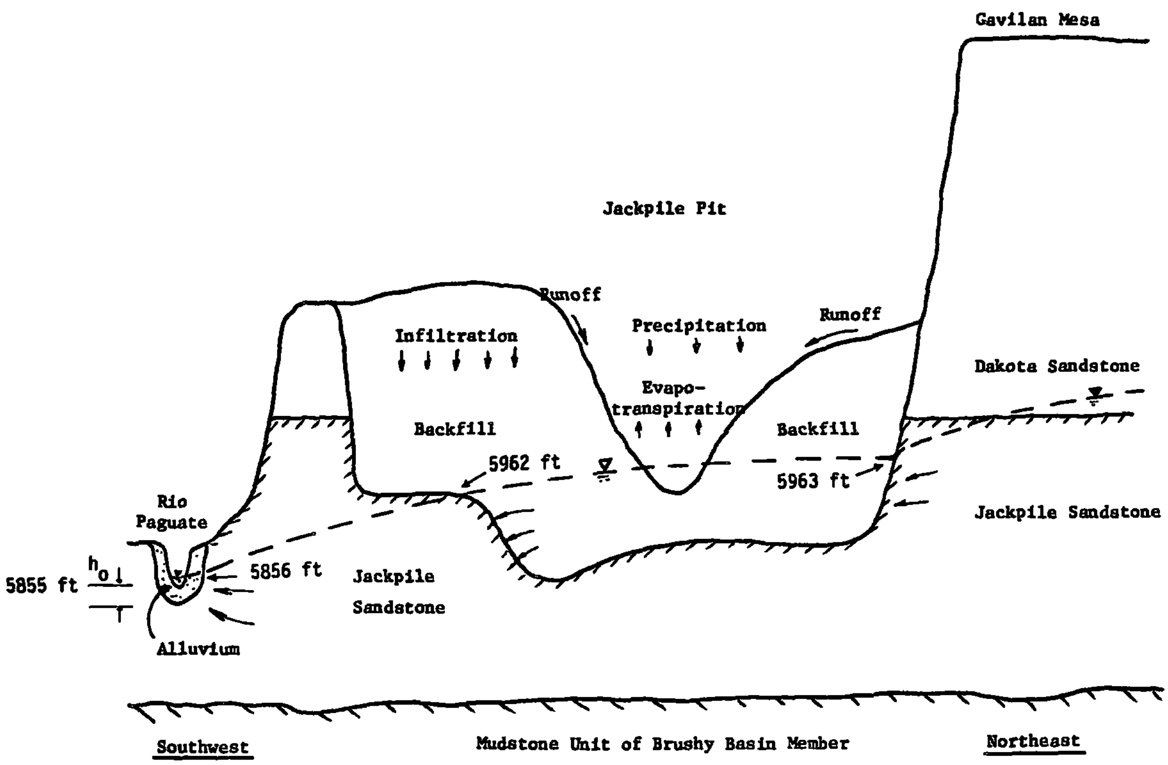



Figure 5.9. Schematic Diagram Showing the Cross Section of Selected Groundwater Flow Path through the Jackpile Pit.

Table 5.3. Selected Data for Groundwater Flow Analysis for Jackpile Pit

| Symbol | Parameter | Values†[1] |
|---|---|---|
| P | Annual average precipitation | 9.5 in |
| A | Drainage area for Jackpile pit | 475 ac |
| $h_o$ | Flow depth in Rio Paguate | 0, 2, 5 ft |
| $K_j$ | Hydraulic conductivity of Jackpile sandstone | 0.3 ft/day |
| $K_b$ | Hydraulic conductivity of backfill material | 190 ft/day |
| $K_a$ | Hydraulic conductivity of alluvium | 22 ft/day |
| $I_j$ | Equilibrium hydraulic gradient in Jackpile | 0.03 |
| $B_j$ | Saturated thickness of Jackpile sandstone | 120 ft |
| L | Horizontal distance from Rio Paguate: | |
| | alluvium | 500 ft |
| | Jackpile sandstone | 1700 ft |
| | backfill | 6200 ft |
| | Jackpile sandstone | 7200 ft |

†[1] Conversions: 1 in = 2.54 cm; 1 ft = 0.3048 m; 1 ac = $4.046 \times 10^3$ $m^2$.

local infiltration of precipitation was taken into account in the same way as was done for the South Paguate pit (Sec. 5.5).

The results showing the differences ($\Delta h$) between the water level in backfill at the northern end of the Jackpile pit and in the stream bed are presented in Table 5.4. For the maximum discharge conditions, the maximum $\Delta h$ would be about 33 m (108 ft) after reclamation. The streambed of the Rio Paguate is at an elevation of about 1785 m (5855 ft) above mean sea level near the southwestern end of the pit (Hydro-Search 1979). Therefore, the maximum elevation of the equilibrium groundwater level at the northern end of the Jackpile pit would be about 1818 m (5963 ft). The results of the calcuations indicated that the position of the groundwater level in the Jackpile pit (Fig. 5.9) would be only about 0.3 m (1 ft) less than the maximum elevation. Furthermore, in contrast to the Paguate pit area, the equilibrium groundwater levels in the Jackpile pit area would not vary significantly with changing water levels in the Rio Paguate. This is because the Jackpile sandstone has a low transmissivity, which would negate the influence of water-level changes in the stream.

Table 5.4. Equilibrium Groundwater Levels in the Jackpile Pit†[1]

| Bedrock Discharge into Backfill, $q_s$ ($ft^3$/day/ft) | Rate of Infiltration into Backfill, $q_i$ ($ft^3$/day/ft) | Total Discharge in in Backfill, q ($ft^3$/day/ft) | Assumed River Flow Depth, $h_o$ (ft) | Water Level above Streambed, $\Delta h$ (ft) |
|---|---|---|---|---|
| 2.2 | 0 | 2.2 | 0 | 67 |
| | | | 2 | 68 |
| | | | 5 | 70 |
| 2.2 | 0.9 | 3.1 | 0 | 87 |
| | | | 2 | 88 |
| | | | 5 | 90 |
| 2.2 | 1.8 | 4.0 | 0 | 106 |
| | | | 2 | 107 |
| | | | 5 | 108 |

†[1] Conversion: 1 ft = 0.3048 m.

The results shown in Table 5.4 indicate that the rate of infiltration into the backfill in the Jackpile pit can have significant effect on the calculated groundwater level. However, the sandstone would slow the groundwater flow and leave ample time for the infiltrated water in the pit backfill to evaporate. Any discharge into the Rio Paguate as a result of infiltration would be minimal and would not greatly affect the groundwater regime in the area.

References for Section 5

Harr, M.E. 1962. "Groundwater and Seepage." McGraw-Hill Book Co., New York, NY. pp. 40-48.

Hydro-Search, Inc. 1979. "Hydrologic Relationships, Rabbit Ear and P-10 Holding Ponds, Jackpile-Paguate Mine, Valencia County, New Mexico." Prepared for Anaconda Company. p. 48.

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Polubarinova-Kochina, P. Ya. 1962. "Theory of Ground Water Movement." Translated by J.M.R. DeWiest. Princeton University Press, Princeton, NJ. pp. 404-423.

## APPENDIX A. DESCRIPTION OF DECOMMISSIONING-RECLAMATION ALTERNATIVES

### A.1 ALTERNATIVE A - NO ACTION

#### A.1.1 Objectives

40 CFR Part 1502.14 requires that all environmental impact statements address the no-action alternative. For this project, no action means that the Department of the Interior would not approve any reclamation alternative. Thus, no reclamation would be conducted.

#### A.1.2 Future Land Uses

- None - except mining.
- Specifically excluded are any human or livestock access to the site, except worker access to collect environmental monitoring data, to perform site maintenance, or for additional mining activities.

#### A.1.3 Reclamation Measures

Open Pits

- No action.

Protore Stockpiles

- No action.

Waste Piles

- No action.

Site Stability and Drainage

- No action.

Structures

- No action.

Revegetation

- No action.

Monitoring

- Continue present monitoring programs. Guard site to prevent unauthorized access.

## A.2 ALTERNATIVE B - NO FUTURE USE (SACRIFICE AREA)

### A.2.1 Objectives

- Reduce the adverse offsite environmental impacts.
- Prevent human and livestock access to the site.
- Monitor the site to the extent necessary to provide early detection of any developing environmental hazards that could impact the offsite environment.

### A.2.2 Future Land Uses

- None - except mining.
- Specifically excluded are any human or livestock access to the site, except worker access to collect environmental monitoring data, to perform site maintenance, or for additional mining activities.

### A.2.3 Reclamation Measures

Open Pits

- No action (see revegetation).

Protore

- Relocate the protore* piles that lie adjacent to the Rio Moquino and Rio Paguate to other protore piles.
- Cover all protore piles with one foot of topsoil.

Waste Piles

- No action.

Site Stability and Drainage

- Relocate all protore and waste material that lies within 200 feet of the Rio Paguate and Rio Moquino to other protore and waste piles.
- Construct a levee along the north side of the Rio Paguate to prevent the flooding of the North Paguate Pit.

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*Any material containing equal to or more than 0.02% $U_3O_8$ (≅55 pCi/g U-238).

- Construct a series of sediment traps in all major arroyos that have the potential of encroaching upon waste dumps.

- Construct erosion control berms along the Rio Moquino and Rio Paguate to prevent surface runoff from entering the rivers.

Structures

- Blast all underground mine entries closed. Backfill vent holes with waste to within 10 feet of the surface, and place a 10-foot cement surface plug.

- Remove crusher, tipple, mining equipment, all buildings, sewage systems, and power lines.

- Remove all pumps, and cap all water wells.

Revegetation

- Obtain topsoil from the four existing topsoil stockpiles. Place one foot of topsoil on all disturbed areas, including open pits, protore, and waste dumps.

- Revegetate all disturbed areas with plant species that will minimize soil erosion.

- Prevent any livestock grazing of the site.

Monitoring

- Fence the entire site and the proposed location of Highway 279 with six-foot chainlink.

- Continue monitoring (by Anaconda) for five years after reclamation is completed. Subsequent monitoring to be performed by the Department of the Interior.

- The Pueblo of Laguna and Bureau of Indian Affairs would prevent unauthorized access to the site.

## A.3 ALTERNATIVE C1 - GRAZING USE (APPLICANT'S PROPOSAL)

### A.3.1 Objectives

- Mitigate the effects of mining disturbance on the leased lands.

- Mitigate safety and health hazards.

- Protect the environment, with particular concern for the water resources.

- Enhance the visual resources of the area.

### A.3.2 Future Land Uses

- Livestock grazing.
- Specifically excluded are habitation, farming, and construction of commercial or industrial facilities.

### A.3.3 Reclamation Measures

Open Pits

- Backfill to three feet above the groundwater-recovery level (as determined by Anaconda).
- Backfill, with protore, waste dumps H and J, and excess material obtained from the sloping of waste piles and the clearing of stream channels.
- Cover the backfill material with four feet of overburden and one foot of topsoil.
- Buttress the west side of the Gavilan Mesa highwall (the top of the highwall may be cut back by blasting or hauling).
- Fence the north, west, and south sides of the North and South Paguate Pits with six-foot chainlink.
- Scale all other highwalls.

Protore Stockpiles

- Use all protore as backfill material.

Waste Piles

- Relocate dumps H and J to the open pits as backfill material.
- Cover dumps that contain hazardous material on their outer surface with four feet of non-hazardous material and one foot of topsoil.
- Cover dumps that do not contain hazardous material on their outer surface with one foot of topsoil.
- Leave previously topsoiled and revegetated dumps undisturbed (except to reseed and stabilize slopes, as necessary).
- Reduce the angle of some dump slopes. The slopes would vary from 2:1 to 3:1, with an average grade of 2.25:1. The slopes would contain terraces and rock-lined drop structures to drain surface runoff of the piles.

Site Stability and Drainage

- Remove all Jackpile sandstone waste that lies within 200 feet of the Rio Moquino and Rio Paguate.

- Armor arroyo headcuts that have the potential for encroaching upon waste dumps that contain Jackpile sandstone.
- Construct erosion control berms on the perimeter of all waste piles. Construct a series of erosion-control berms on the top of all waste piles to spread out surface runoff.
- Remove waste dump J and protore stockpiles 17-BC and 6-B to unblock the ephemeral drainage on the south side of the mine. The two blocked drainages on the north and south sides of Gavilan Mesa will remain blocked.
- The remainder of the site will drain to the Rio Paguate and Rio Moquino.
- Modify waste dumps as previously discussed.

<u>Structures</u>

- Construct a cement bulkhead 680 feet below the collar of the P-10 decline, and backfill to the surface. Place a 10-foot cement surface plug in each vent hole. All other mine entries would be covered by backfilling, or have been previously plugged.
- Remove crusher, tipple, and all other mining equipment.
- Salvage all rail spur track, ties, and the Quirk loading dock.
- Remove ballast and contaminated soils to the open pits.
- Clear the four main roads on the site and the parking areas on Lease Number 4 of Jackpile sandstone until values of twice background are achieved. These roads and parking areas will remain. Clear all other roads, parking areas, and associated structures of Jackpile sandstone until values of twice background are achieved, and recontour these areas to conform to the surrounding terrain.
- Remove all power lines, except those on Lease Number 4 (which serve the buildings on Lease Number 4 and areas exterior to the lease).
- Remove all pumps, and cap all water wells.
- Clean up P-10 mine buildings and the New Shop until radiological values of twice background are achieved. Leave these buildings and sewage systems intact. Remove all other buildings, including the employee housing, Jackpile Shop, Open Pit Offices, and powder magazines.

<u>Revegetation</u>

- Obtain topsoil from the four existing topsoil stockpiles and from a topsoil borrow area along the Rio Moquino. Place one foot of topsoil on all backfill material and waste dumps.

- Revegetate all disturbed areas to approximately the species density and diversity of the surrounding undisturbed land. Revegetate with predominantly native grasses and shrubs that are conducive to the grazing of livestock.

- Prevent grazing for three years following reclamation.

Monitoring

- Continue monitoring (by Anaconda) of surface water, groundwater, air quality, subsidence, revegetation success, and concentration of toxic elements in revegetation species for a period of three years following the completion of reclamation activities.

- The Bureau of Land Management and the Bureau of Indian Affairs would monitor every aspect of the reclamation activities to ensure compliance with all reclamation requirements. The Pueblo of Laguna and the Bureau of Indian Affairs would control future land use on the site, and would prevent any uses not provided for by this reclamation alternative.

## A.4 ALTERNATIVE C2 - GRAZING USE (DEVELOPED BY THE EIS TASK FORCE)

### A.4.1 Objectives

- Fulfill the evaluation criteria to the greatest extent practicable without imposing unreasonably costly reclamation measures on Anaconda.

- Accommodate the following land uses:

Future Land Uses

- Livestock grazing.

- Specifically excluded are habitation and farming.

### A.4.3 Reclamation Measures

Open Pits

- Backfill to 10 feet above the groundwater-recovery level (as determined by the EIS Task Force).

- Use waste dumps H and J, excess material obtained from the sloping of waste piles, protore that contains less than 0.033% $U_3O_8$, and overburden from waste dumps as backfill.

- Cover the backfill material with one foot of overburden and one foot of top soil.

- Buttress the west side of the Gavilan Mesa highwall (the top of the highwall may be cut back by blasting). Cut a 15-foot-deep trench in east end of Gavilan Mesa.

- Slope the North Paguate highwall to a 3 to 1 slope and cover with two feet of topsoil.
- Trim the top edge of all highwalls (except Gavilan Mesa) to a 45-degree angle. Scale all other highwalls.

Protore Stockpiles

- Relocate all protore piles that contain greater than 0.033% $U_3O_8$ to the open pits above the groundwater-recovery level or to other stable locations.
- Cover the piles with four feet of overburden and one foot of soil.

Waste Piles

- Relocate dumps H and J to the open pits as backfill material.
- Cover dumps that contain hazardous material on their outer surface with four feet of non-hazardous material and 1 foot of topsoil.
- Cover dumps that do not contain hazardous material on their outer surface with two feet of topsoil.
- Leave previously topsoiled and revegetated dumps undisturbed (except to reseed, as necessary).
- Reduce all dump slopes to a 3:1 grade with the exception of FD-2, which would be reduced in height and slope to 2.25:1 and benched. All dump slopes and tops would be contour furrowed.

Site Stability and Drainage

- Remove all protore and waste material that lies within 200 feet of the Rio Paguate and Rio Moquino. Construct a permanent cement base for the Rio Moquino immediately above its confluence with Rio Paguate. Construct a levee along the north side of the Rio Paguate to prevent the flooding of the North Paguate Pit.
- Create an artificial watershed divide south of dumps Y, Y-Z, and I to inhibit arroyo head cutting, and armor the arroyo north of dump FD-3.
- Contour furrow all pit areas.
- Slightly slope all dump tops away from their outer slopes. Contour furrow all dump tops.
- Remove waste dump J and protore stockpiles 17-BC and 6-B to unblock the ephemeral drainage on the south side of the mine. The two blocked drainages on the north and south sides of Gavilan Mesa will remain blocked. The remainder of the site will drain to the Rio Paguate and Rio Moquino.

- Modify waste dumps as previously discussed.

Structures

- Construct a cement bulkhead 680 feet below the collar of the P-10 decline, and backfill to the surface. Bulkhead and fill the Alpine Mine entry. Backfill vent holes with waste to within 10 feet of the surface, and place a 10-foot cement surface plug. All other mine entries would be covered by backfilling, or have been previously plugged.

- Salvage all rail spur track, ties, and the Quirk loading dock. Remove ballast and contaminated soils to the open pits.

- Remove ballast and contaminated soils to the open pits. Cover disturbed area with one foot of topsoil.

- Clear the four main roads on the site of radiologically contaminated material until values of twice background are achieved. These roads will remain. Clear all other roads and associated structures of radiologically contaminated material until values of twice background are achieved, and recontour these areas to conform to the surrounding terrain.

- Clear the Woodrow Mine area of radiologically contaminated materials, and cover with soil so that radiological values of twice background are achieved.

- Remove crusher, tipple, mining equipment, all buildings, sewage systems, and power lines.

- Remove all pumps, and cap all water wells.

Revegetation

- Obtain soil from the four existing topsoil stockpiles, from the soil borrow areas along the Rio Moquino, and from the east side of Gavilan Mesa. Place two feet of soil on all waste dumps that contain Jackpile sandstone on their outer surface, and all protore piles.

- Revegetate all disturbed areas to approximate the species density and diversity of the surrounding undisturbed land. Revegetate with predominantly native grasses and shrubs that are conducive to the grazing of livestock.

- Prevent grazing for three years following reclamation.

Monitoring

- Continue monitoring (by Anaconda) of surface water, groundwater, air quality, subsidence, revegetation success, and concentration of toxic elements in revegetation species for a period of five years following the completion of reclamation activities. Subsequent monitoring to be performed by the Department of the Interior.

- The Bureau of Land Management and the Bureau of Indian Affairs would monitor every aspect of the reclamation activities to ensure compliance with all reclamation requirements. The Pueblo of Laguna and Bureau of Indian Affairs would control future land use on the site, and would prevent any uses not provided for by this reclamation alternative.

- Access prior to and during reclamation would be controlled by Anaconda.

## A.5 ALTERNATIVE D - MAXIMUM SITE USE

### A.5.1 Objectives

- Fulfill the evaluation criteria to the greatest extent practicable without imposing unreasonably costly reclamation measures on Anaconda.

- Accommodate the following land uses:

### A.5.2 Future Land Uses

- Livestock grazing, construction, and use of commercial and industrial facilities such as office space, light manufacturing and storage, recreation, and additional mining activities.

- Specifically excluded are habitation and farming.

### A.5.3 Reclamation Measures

#### Open Pits

- Backfill to 10 feet above the groundwater-recovery level (as determined by the EIS Task Force).

- Use waste dumps H and J, excess material obtained from the sloping of waste piles, protore that contains less than 0.033% $U_3O_8$, and overburden from waste dumps as backfill.

- Cover the backfill material with one foot of topsoil.

- Buttress the west side of the Gavilan Mesa highwall (the top of the highwall may be cut back by blasting). Cut a 15-foot-deep trench in the east end of Gavilan Mesa.

- Slope the North Paguate highwall to a 3 to 1 slope and cover with two feet of topsoil.

- Trim the top edge of all highwalls (except Gavilan Mesa) to a 45-degree angle. Scale all other highwalls.

#### Protore Stockpiles

- Relocate all protore piles that contain greater than 0.033% uranium to the open pits above the groundwater recovery level, or to other stable locations.

- Cover the piles with four feet of overburden and one foot of soil.

Waste Piles

- Relocate dumps H and J to the open pits as backfill material.
- Cover dumps that contain Jackpile sandstone on their outer surface with four feet of overburden and one foot of topsoil.
- Cover dumps that do not contain Jackpile sandstone on their outer surface with two feet of soil.
- Leave previously topsoiled and revegetated dumps undisturbed (except to reseed and modify slopes as necessary).
- Reduce all dump slopes to a 3:1 grade with the exception of dump FD-2, which would be reduced in height and slope to 2.25:1 and benched. All dump slopes and tops would be contour furrowed.

Site Stability and Drainage

- Remove all protore and waste material that lies within 200 feet of the Rio Paguate and Rio Moquino. Construct a permanent cement base for the Rio Moquino immediately above its confluence with the Rio Paguate. Construct a levee along the north side of the Rio Paguate to prevent the flooding of the North Paguate Pit.
- Create an artificial watershed divide south of dumps Y, Y-Z, and I to inhibit arroyo-head cutting, and armor the arroyo north of dump FD-3. Contour furrow all pit areas.
- Slightly slope all dump tops away from their outer slopes. Contour furrow all dump tops.
- Remove waste dump J and protore stockpiles 17-BC and 6-B to unblock the ephemeral drainage on the south side of the mine. The two blocked drainages on the north and south sides of Gavilan Mesa would remain blocked. The remainder of the site, except the open pits, would drain to the Rio Paguate and Rio Moquino.
- Modify waste dumps as previously discussed.

Structures

- Construct a cement bulkhead 680 feet below the collar of the P-10 decline and backfill to the surface. Bulkhead and fill the Alpine Mine entry. Backfill vent holes with waste to within 10 feet of the surface and place a 10-foot cement surface plug. All other mine entries would be covered by backfilling or have been previously plugged.
- Salvage all rail spurtracks, ties, and Quirk loading dock. Remove ballast and contaminated soils to the open pits.

- Clean up radiological hot spots along the rail spur until values of twice background are achieved. Remove the Quirk loading dock. Leave the rail spur intact.

- Clear the four main roads on the site and the parking areas for the geology building, Open Pit Offices, P-10 mine buildings, New Shop, and Old Shop of radiologically contaminated material until values of twice background are achieved. These roads and parking areas will remain. Clear all other roads and associated structures of radiologically contaminated material until values of twice background are achieved and recontour these areas to conform to the surrounding terrain.

- Leave all power lines intact.

- Remove all pumps and cap all water wells.

- Clean up the P-10 mine buildings, New Shop, Old Shop, geology buildings, and the Open Pit Offices until radiological values of twice background are achieved. Leave these buildings and their sewage systems intact. Remove all other buildings, including the employee housing and powder magazine.

- Clear the Woodrow Mine area of radiologically contaminated materials, and cover with soil so that radiological values of twice background are achieved.

Revegetation

- Obtain soil from the four existing topsoil stockpiles, from the soil borrow areas along the Rio Moquino, and from the east side of Gavilan Mesa. Place one foot of soil on all backfill material and dumps that do not contain Jackpile sandstone on their outer surface. Place two feet of soil on all waste dumps that contain Jackpile sandstone on their outer surface, and all protore piles.

- Revegetate all disturbed areas to approximate the species density and diversity of the surrounding undisturbed land. Revegetate with predominantly native grasses and shrubs that are conducive to the grazing of livestock.

- Prevent grazing for five years following reclamation.

Monitoring

- Continue monitoring (by Anaconda) of surface water, groundwater, air quality, subsidence, revegetation success, and concentration of toxic elements in revegetation species for a period of five years following the completion of reclamation activities. Subsequent monitoring to be performed by the Department of the Interior.

- The Bureau of Land Management and the Bureau of Indian Affairs would monitor every aspect of the reclamation activities to ensure compliance with all reclamation requirements. The Pueblo of Laguna and Bureau of Indian Affairs would control future land use on the site, and would prevent any uses not provided for by this reclamation alternative. Access prior to and during reclamation would be controlled by Anaconda.

# APPENDIX B. METEOROLOGICAL INPUT PARAMETERS FOR UDAD CODE

Table B.1. Annual Relative Frequence of Occurrence of Wind Speed and Direction--Sum of All Stability Classes†[1,2]

| WIND DIRECTION | 0 - 3 | 4 - 6 | 7 - 10 | 11 - 16 | 17 - 21 | OVER 21 | ROW TOTALS |
|---|---|---|---|---|---|---|---|
| | WIND SPEED, KNOTS | | | | | | |
| N | 0.01126 | 0.01126 | 0.01126 | 0.01126 | 0.00754 | 0.00754 | 0.06015 |
| NNE | 0.01126 | 0.01126 | 0.00945 | 0.00945 | 0.00191 | 0.00191 | 0.04526 |
| NE | 0.01509 | 0.01509 | 0.00694 | 0.00694 | 0.00312 | 0.00312 | 0.05029 |
| ENE | 0.00875 | 0.00875 | 0.00945 | 0.00945 | 0.00060 | 0.00060 | 0.03762 |
| E | 0.00252 | 0.00252 | 0.00312 | 0.00312 | 0.0 | 0.0 | 0.01127 |
| ESE | 0.00191 | 0.00191 | 0.00372 | 0.00372 | 0.0 | 0.0 | 0.01127 |
| SE | 0.00945 | 0.00945 | 0.00754 | 0.00754 | 0.00060 | 0.00060 | 0.03521 |
| SSE | 0.04335 | 0.04335 | 0.03018 | 0.03018 | 0.00060 | 0.00060 | 0.14826 |
| S | 0.01257 | 0.01257 | 0.02324 | 0.02324 | 0.00060 | 0.00060 | 0.07282 |
| SSW | 0.00372 | 0.00372 | 0.00754 | 0.00754 | 0.0 | 0.0 | 0.02253 |
| SW | 0.00754 | 0.00754 | 0.01378 | 0.01378 | 0.00121 | 0.00121 | 0.04506 |
| WSW | 0.01126 | 0.01126 | 0.01328 | 0.01328 | 0.00191 | 0.00191 | 0.05291 |
| W | 0.00252 | 0.00252 | 0.00322 | 0.00322 | 0.0 | 0.0 | 0.01147 |
| WNW | 0.00372 | 0.00372 | 0.00754 | 0.00754 | 0.0 | 0.0 | 0.02253 |
| NW | 0.01378 | 0.01378 | 0.01630 | 0.01630 | 0.00121 | 0.00121 | 0.06256 |
| NNW | 0.07795 | 0.07795 | 0.04627 | 0.04627 | 0.03118 | 0.03118 | 0.31080 |
| COLUMN TOTALS: | 0.23667 | 0.23667 | 0.21284 | 0.21284 | 0.05049 | 0.05049 | 1.00001 |

†[1] Values are for rotated wind direction (see Sec. 2.4).

†[2] 1 knot = 0.51444 meter/second.

## APPENDIX C. HYDROLOGY

Table C.1. Summary of Water Quality Sampling Results--February 1979 - March 1982†[1] (Concentrations in ppm except as noted)

| Location | pH†[2] | TDS | Cond.†[2] | $HCO_3^-$ | Cl- | $SO_4^-$ | Na+ |
|---|---|---|---|---|---|---|---|
| Rio Paguate upstream | | | | | | | |
| Range | 7.9-8.5 | 304-1316 | 420-1550 | 46-376 | 9-16 | 76-653 | 23-97 |
| Average | 8.2 | 609 | 784 | 315 | 12 | 185 | 37 |
| Rio Moquino Upstream | | | | | | | |
| Range | 8.0-8.45 | 1067-2538 | 1080-2850 | 195-396 | 8-26 | 581-1650 | 1-322 |
| Average | 8.2 | 1622 | 1938 | 263 | 17 | 968 | 172 |
| Rio Paguate above the confluence | | | | | | | |
| Range | 7.9-8.6 | 397-1324 | 570-1570 | 198-361 | 7-25 | 97-1249 | 24-210 |
| Average | 8.3 | 781 | 943 | 288 | 14 | 343 | 63 |
| Rio Moquino above the confluence | | | | | | | |
| Range | 7.9-8.43 | 692-2877 | 520-3050 | 195-420 | 10-27 | 227-1795 | 41.6-353 |
| Average | 8.2 | 1827 | 2210 | 271 | 18 | 1107 | 214 |
| Rio Paguate Ford Crossing | | | | | | | |
| Range | 7.6-8.4 | 1026-2347 | 1050-3000 | 183-351 | 11-30 | 544-1404 | 100-325 |
| Average | 8.2 | 1673 | 2081 | 285 | 20 | 1020 | 188 |
| Paguate Reservoir | | | | | | | |
| Range | 7.39-8.6 | 934-4800 | 800-5350 | 30-276 | 9-105 | 511-3090 | 63-625 |
| Average | 8.0 | 1934 | 2332 | 232 | 30 | 1243 | 214 |
| Jackpile #4 | | | | | | | |
| Range | 8.1-8.8 | 635-1053 | 900-1800 | 325-596 | 9-32 | 300-365 | 202-350 |
| Average | 8 | 890 | 1332 | 368 | 18 | 325 | 288 |
| Jackpile New Shop | | | | | | | |
| Range | 8.0-8.5 | 1111-1629 | 1500-2500 | 346-415 | 20-32 | 653-755 | 336-600 |
| Average | 8.1 | 1443 | 1964 | 388 | 27 | 674 | 446 |
| Jackpile Old Shop | | | | | | | |
| Range | 7.81-8.4 | 1397-4005 | 1900-4700 | 214-347 | 1-120 | 622-2480 | 274-560 |
| Average | 8.2 | 2640 | 3056 | 287 | 67 | 1576 | 440 |

Table C.1. Continued

| Location | K+ | $Ca^{++}$ | $Mg^{++}$ | $NO_3^-$ | $F^-$ | $SiO_2$ | $Mn^{++}$ |
|---|---|---|---|---|---|---|---|
| Rio Paguate upstream | | | | | | | |
| Range | 3-25 | 62-160 | 20-78 | <1-1.4 | <0.1-0.81 | 14-36 | <0.1-0.3 |
| Average | 7 | 91 | 37 | 0.28 | 0.4 | 28 | <0.1 |
| Rio Moquino upstream | | | | | | | |
| Range | 7-24 | 107-350 | 6-180 | <1-2.9 | <0.1-0.9 | 9.3-30 | <0.1-0.10 |
| Average | 13 | 158 | 96 | <1 | <0.5 | 17 | <0.1 |
| Rio Paguate above the confluence | | | | | | | |
| Range | 3-19 | 37-202 | 20-151 | <1-2 | <0.1-0.70 | 13-34.7 | <0.1-0.10 |
| Average | 8 | 90 | 54 | <1 | 0.4 | 24 | <0.1 |
| Rio Moquino above the confluence | | | | | | | |
| Range | 5.3-28 | 13-313 | 2-175 | <1-2 | <0.1-0.96 | 8-36 | <0.1-0.13 |
| Average | 14 | 168 | 108 | <1 | 0.6 | 17 | <0.1 |
| Rio Paguate Ford Crossing | | | | | | | |
| Range | 5.4-27 | 105-274 | 44-160 | <1-7 | <0.1-0.81 | 3-25 | <0.1-0.113 |
| Average | 14 | 160 | 111 | <1 | 0.53 | 17 | <0.1 |
| Paguate Reservoir | | | | | | | |
| Range | 2-84 | 136-309 | 0.013-330 | <1-5 | <0.1-1.0 | 0.2-18 | <0.1-0.10 |
| Average | 24 | 198 | 105 | <1 | 0.55 | 6 | <0.1 |
| Jackpile #4 | | | | | | | |
| Range | 1-8.2 | 3-6.4 | <1-55 | <1-2.7 | <0.1-1.6 | 5.6-13 | <0.1-0.10 |
| Average | 3 | 4 | 3 | 1 | 1.0 | 10 | <0.1 |
| Jackpile New Shop | | | | | | | |
| Range | 2-11 | 11-21 | 1-3 | <1-3 | <0.1-1.5 | 7.4-17 | <0.1-0.10 |
| Average | 6 | 15 | 2 | 1 | 1.0 | 13 | <0.1 |
| Jackpile Old Shop | | | | | | | |
| Range | 1-20 | 30-386 | 26-246 | <1-58 | <0.1-1.05 | 4.3-18 | <0.1-0.10 |
| Average | 11 | 189 | 123 | 37 | 0.6 | 9 | <0.1 |

Table C.1. Continued

| Location | As | Ba | Cd | Cr | Pb | Hg | Se |
|---|---|---|---|---|---|---|---|
| Rio Paguate upstream | | | | | | | |
| Range | <0.005-0.009 | <0.05-0.56 | <0.001-0.001 | <0.005-0.008 | <0.0005-0.055 | <0.0005-0.0010 | <0.01-0.01 |
| Average | 0.005 | 0.1 | <0.001 | <0.005 | 0.012 | <0.0005 | 0.01 |
| Rio Moquino upstream | | | | | | | |
| Range | <0.005-0.028 | <0.05-0.72 | <0.001-0.001 | <0.005-0.007 | <0.005-0.047 | <0.0005-0.0005 | <0.01-0.01 |
| Average | 0.005 | 0.09 | <0.001 | 0.005 | 0.012 | <0.0005 | <0.01 |
| Rio Paguate above the confluence | | | | | | | |
| Range | <0.005-0.008 | <0.05-0.60 | <0.001-0.001 | <0.005-0.007 | <0.005-0.060 | <0.0005-0.0005 | <0.01-0.01 |
| Average | 0.005 | 0.08 | <0.001 | <0.005 | 0.011 | <0.0005 | <0.01 |
| Rio Moquino above the confluence | | | | | | | |
| Range | <0.005-0.009 | <0.05-0.64 | <0.001-0.001 | <0.005-0.006 | <0.005-0.14 | <0.0005-0.0009 | <0.01-0.01 |
| Average | <0.005 | 0.09 | 0.001 | <0.005 | 0.018 | <0.0005 | <0.01 |
| Rio Paguate Ford Crossing | | | | | | | |
| Range | <0.005-0.007 | <0.05-0.28 | <0.001-0.001 | <0.005-0.009 | <0.005-0.05 | <0.0005-0.0010 | <0.01-0.01 |
| Average | <0.005 | 0.09 | <0.001 | <0.005 | 0.015 | <0.0005 | <0.01 |
| Paguate Reservoir | | | | | | | |
| Range | <0.005-0.011 | <0.05-0.44 | <0.001-0.001 | <0.005-0.006 | <0.005-0.059 | <0.0005-0.0005 | <0.01-0.01 |
| Average | 0.007 | 0.08 | <0.001 | <0.005 | 0.016 | <0.0005 | <0.01 |
| Jackpile #4 | | | | | | | |
| Range | <0.005-0.007 | <0.05-0.60 | <0.001-0.001 | <0.005-0.005 | <0.005-0.055 | <0.0005-0.0011 | <0.01-0.01 |
| Average | <0.005 | 0.09 | <0.001 | <0.005 | 0.012 | <0.0005 | <0.01 |
| Jackpile New Shop | | | | | | | |
| Range | 0.005-0.008 | <0.05-0.60 | <0.001-0.001 | <0.005-0.008 | <0.005-0.065 | <0.0005-0.0005 | <0.01-0.01 |
| Average | 0.006 | 0.06 | <0.001 | <0.005 | 0.02 | <0.0005 | <0.01 |
| Jackpile Old Shop | | | | | | | |
| Range | <0.005-0.008 | <0.05-0.66 | <0.001-0.008 | <0.005-0.014 | <0.005-0.14 | <0.0005-0.0005 | <0.01-0.36 |
| Average | 0.006 | 0.06 | <0.001 | <0.005 | 0.018 | <0.0005 | 0.18 |

## Table C.1. Continued

| Location | Cu | Fe | Zn | Mo | Ni | V | U | Ra-226†2 |
|---|---|---|---|---|---|---|---|---|
| Rio Paguate upstream | | | | | | | | |
| Range | <0.001-0.032 | <0.1-0.31 | 0.002-0.052 | <0.01-0.02 | <0.005-0.005 | <0.05-0.02 | 0.001-0.015 | 0.02-1.20 |
| Average | 0.005 | 0.06 | 0.008 | <0.01 | <0.005 | <0.05 | 0.006 | 0.35 |
| Rio Moquino upstream | | | | | | | | |
| Range | <0.001-0.014 | <0.01-0.31 | 0.003-0.046 | <0.01-0.01 | <0.005-0.011 | <0.05-0.02 | 0.001-0.12 | 0.02-0.60 |
| Average | 0.004 | <0.10 | 0.013 | <0.01 | <0.005 | <0.05 | 0.008 | 0.28 |
| Rio Paguate above the confluence | | | | | | | | |
| Range | 0.001-0.019 | <0.1-0.31 | 0.002-0.081 | <0.01-0.01 | <0.005-0.005 | <0.05-0.02 | 0.007-0.296 | 0.32-12.17 |
| Average | 0.005 | <0.10 | 0.010 | <0.01 | <0.005 | <0.05 | 0.066 | 3.04 |
| Rio Moquino above the confluence | | | | | | | | |
| Range | <0.001-0.010 | <0.1-0.3 | <0.001-0.18 | <0.01-0.01 | <0.005-0.005 | <0.05-0.02 | 0.007-0.138 | 0.24-4.19 |
| Average | 0.004 | <0.10 | 0.012 | <0.01 | <0.005 | <0.05 | 0.043 | 1.26 |
| Rio Paguate Ford Crossing | | | | | | | | |
| Range | <0.001-0.025 | <0.1-3.12 | <0.001-0.038 | <0.01-0.01 | <0.005-0.005 | <0.05-0.02 | 0.017-2.147 | 0.77-12.79 |
| Average | 0.005 | <0.15 | 0.01 | <0.01 | <0.005 | <0.05 | 0.239 | 3.73 |
| Paguate Reservoir | | | | | | | | |
| Range | 0.002-0.012 | <0.1-0.30 | 0.003-0.020 | <0.01-0.01 | <0.005-0.005 | <0.05-0.05 | 0.004-1.214 | 0.05-3.01 |
| Average | 0.005 | <0.10 | 0.01 | <0.01 | <0.005 | <0.05 | 0.236 | 1.03 |
| Jackpile #4 | | | | | | | | |
| Range | 0.003-0.014 | <0.1-1.0 | <0.001-0.041 | <0.01-0.02 | <0.005-0.012 | <0.05-0.05 | 0.001-0.015 | 0.06-1.90 |
| Average | 0.004 | <0.10 | 0.012 | <0.01 | <0.005 | <0.05 | 0.007 | 0.58 |
| Jackpile New Shop | | | | | | | | |
| Range | 0.001-0.021 | <0.1-0.2 | 0.008-0.210 | <0.01-0.02 | <0.005-0.005 | <0.05-0.05 | 0.001-0.022 | 0.66-4.64 |
| Average | 0.005 | <0.10 | 0.055 | 0.01 | <0.005 | <0.05 | 0.009 | 2.55 |
| Jackpile Old Shop | | | | | | | | |
| Range | 0.001-0.071 | <0.1-12.4 | <0.001-3.7 | <0.01-0.02 | <0.005-0.005 | <0.05-0.05 | 0.031-0.335 | 0.64-4.93 |
| Average | 0.011 | 0.44 | 0.65 | 0.01 | <0.005 | <0.05 | 0.164 | 2.48 |

†1 Derived from water samples collected monthly by the Anaconda Co. during February 1979 through March 1982.

†2 pH given in standard units; Cond. (conductivity) given in umhos; Ra-226 concentration given in pCi/L.

## C.2. CALCULATION OF THE MOVEMENT OF CONTAMINANTS FROM THE JACKPILE-PAGUATE MINE TO THE TOWN OF LAGUNA

### C.2.1 Mathematical Model

The movement of a dissolved substance through a sorbing confined aquifer is governed by the mass conservation requirement; in addition, a radioactive nuclide will undergo radioactive decay during this movement. This entire process thus will be governed by the equation:

$$\frac{\partial}{\partial t}(nbC) + n_s b \rho_s \frac{\partial S}{\partial t} - \nabla[nD \cdot \nabla C - C\bar{q}] + \lambda n_s b \rho_s S = 0 \qquad \text{(C.2-1)}$$

where:

$C$ = concentration of the solute in solution ($mL^{-3}$)

$S$ = concentration of the solute in the adsorbed phase ($M^{o}$)

$\rho s$ = soil bulk density ($mL^{-3}$)

$\lambda$ = first order rate constant for decay ($T^{-1}$)

$D$ = hydrodynamic dispersion tensor ($L^2T^{-1}$)

$n$ = porosity ($L^{o}$)

$ns$ = $(1 - n)$ and is the volumetric fraction of solid phase ($L^{o}$)

$t$ = time

$b$ = saturated thickness of aquifer ($L$).

With the assumption that the principal axes of the hydrodynamic dispersion tensor correspond to the Cartesian coordinate system, one may write:

$$D_{xx} = d_\ell v, \text{ and} \qquad \text{(C.2-2a)}$$

$$D_{yy} = d_t v , \qquad \text{(C.2-2b)}$$

where:

$D_{xx}$, $D_{yy}$ are the components of hydrodynamic dispersion in the x and y directions of the Cartesian coordinate system ($L^2T^{-1}$)

$d_\ell$ = longitudinal dispersivity ($L$)

$d_t$ = transversal dispersivity ($L$)

$v$ = apparent velocity $q/n$ ($LT^{-1}$)

$q$ = flow in aquifer per unit width ($L^2T^{-1}$)

Assuming that the mechanism of adsorption may be adequately described by a linear equilibrium isotherm, one may write:

$$S = K_d C , \qquad \text{(C.2-3)}$$

where $K_d$ is the distribution coefficient ($L^3M^{-1}$) of the solute, defined as the ratio of the concentration of the solute in the adsorbent to that in the adsorbate. The distribution coefficient is a function of the soil-water pH;

however, in this instance, the value of $K_d$ for the two species under investigation were taken to be constant, i.e., at a pH of 7, as there seems to be no evidence of a possible alteration of the pH from its neutral state during the post-mining stage. Based on Eq. C.2-3, the adsorption rate becomes:

$$\frac{\partial S}{\partial t} = K_d \frac{\partial C}{\partial t} \quad . \tag{C.2-4}$$

Substituting Eqs. C.2-2 and C.2-4 in Eq. C.2-1 and remembering that b and n are assumed constant, one obtains:

$$R_d \frac{\partial C}{\partial t} - D_{xx} \frac{\partial^2 C}{\partial x^2} - D_{yy} \frac{\partial^2 C}{\partial y^2} + v_x \frac{\partial C}{\partial x} + \lambda R_d C = 0 \ , \tag{C.2-5}$$

where $R_d$ is the retardation factor defined as:

$$R_d = 1 + \frac{(1 - n)}{n} \rho_s K_d \ . \tag{C.2-6}$$

The overall effect of the retardation factor is reflected in reduction of the magnitude of the convective, dispersive, and radioactive decay components governing the transport of a dissolved substance in porous media.

C.2.2 Analytical Solution

The method of solving Eq. C.2-1 as adopted here is an analytical one based on the integral-transform method.

The initial and boundary conditions (see Fig. C.1) are given by:

| | | | |
|---|---|---|---|
| $C = C_o$ | $x = 0$ | $y_1 \leq y \leq y_2$ | (C.2-7a) |
| $C = 0$ | $x = 0$ | all other y | (C.2-7b) |
| $\frac{\partial C}{\partial y} \to 0$ | $y \to \pm \infty$ | | (C.2-7c) |
| $\frac{\partial C}{\partial x} \to 0$ | $x \to + \infty$ | | (C.2-7d) |
| $C = 0$ | $t = 0$ | | (C.2-7e) |

then the concentration C (x, y, t) at a particular time t and location (x, y) is given by:

$$C\,(x,y,t) = \frac{C_o x}{4\sqrt{D_x \pi}}\, e^{\left\{\frac{V_x x}{2D_x}\right\}} \cdot \int_{\tau=0}^{t} \frac{e^{-\left(\lambda + \frac{V_x^2}{4D_x}\right)\tau - \frac{x^2}{4D_x \tau}}}{\tau^{3/2}} \tag{C.2-8}$$

$$\cdot \left\{ - \operatorname{erfc}\left(\frac{(y_2 - y)}{2\sqrt{D_y \tau}} + \frac{V_y}{2}\sqrt{\frac{\tau}{D_y}}\right) + \operatorname{erfc}\left(\frac{y_1 - y}{2\sqrt{D_y \tau}} + \frac{V_y}{2}\sqrt{\frac{\tau}{D_y}}\right)\right\} d\tau$$

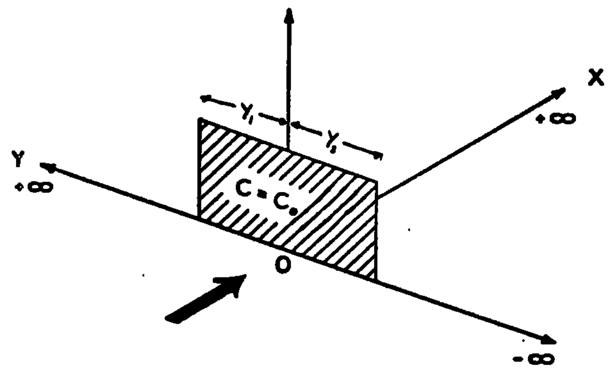


Figure C.1. Two-Dimensional Infinite Groundwater Model Strip Source. ($y_1$ = 500 m; $y_2$ = 500 m)

where:

$$D_x = D_{xx}/R_d \text{ , } D_y = D_{yy}/R_d \text{ , } V_x = v_x/R_d \text{ , and } V_y = v_y/R_d$$

## C.2.3 Assumptions

The long-term impact of migration of radionuclides from the Jackpile-Paguate mines on the groundwater quality of the town of Laguna, situated 10 km (6 mi) south of the site, was calculated based on the following assumptions:

a) The aquifer material is homogeneous, i.e., sandstone with a hydraulic conductivity of 0.12 m/day (0.4 ft/day).

b) The aquifer transmissivity T, written as:

$$T = Kb \text{ ,} \tag{C.2-9}$$

where:

K = saturated hydraulic conductivity ($LT^{-1}$)
b = saturated thickness of aquifer (L)

is assumed constant over the investigated area, implying that its saturated thickness is constant.

c) The groundwater flow is assumed to be under steady-state and isothermal conditions.

d) Groundwater movement is assumed to be unidirectional in the north-south direction. This is a conservative assumption for the prediction of movement of radionuclides from the mine site.

e) The average magnitude of groundwater velocity per unit width of the aquifer is given by Darcy's law, written as:

$$q = -Ti \quad , \qquad (C.2\text{-}10)$$

where:

$q$ = flow in aquifer per unit width ($L^2T^{-1}$)
$i$ = hydraulic gradient ($- \partial\phi/\partial\ell$)
$\phi$ = potential head (L)
$\ell$ = distance along the flow path (L) .

f) The width of a strip source of the raionuclides released to the groundwater is assumed to be 1000 m (3300 ft). The groundwater flow is assumed to be confined within impervious boundaries with a width of 1500 m (4920 ft).

## C.2.4 Estimation of Parameters and Input Data

The apparent velocity was calculated in a conservative manner with the assumption that the piezometric head at the Jackpile pit, which in some spots is presently as low as 1753 m (5750 ft), would reach a value of 1817 m (5960 ft) when the water in the pit would have reached the post-mining equilibrium level. With the piezometric head at the town of Laguna assumed to remain at its present level, about 1753 m (5750 ft), the hydraulic gradient was estimated as follows:

$$i = \frac{(\phi_2 - \phi_1)}{\Delta\ell} = \frac{(1753 - 1817)}{10{,}000} = -6.4 \times 10^{-3} \ .$$

The apparent velocity per unit width and unit thickness of the aquifer is given by:

$$v = q/n = -Ki/n = \frac{0.12 \times 6.4 \times 10^{-3}}{0.15} = 5.12 \times 10^{-3} \text{ m/day}$$

$$= 1.87 \text{ m/year} \ .$$

In the absence of any field or laboratory data, the staff has assumed the value of 2 m and 0.5 m to correspond to the longitudinal and transversal dispersivities for the sandstone, respectively. These values are deemed fairly conservative. Under these assumptions, $D_{xx}$ and $D_{yy}$ in Eq. C.2-4 will correspond to:

$$D_{xx} = d_\ell v = 2 \times 1.87 = 3.74 \text{ m}^2/\text{yr}$$

$$D_{yy} = d_t v = 0.5 \times 1.87 = 0.93 \text{ m}^2/\text{yr} \ .$$

With distribution coefficients, $K_d$, of 100 and 1000 $cm^3/g$ for Ra-226 and Th-230, respectively, the retardation factors (see Eq. C.2-6) for these two species are 567 and 5668, respectively. It can be inferred that the true velocity for each of these species will be reduced by the corresponding retardation factor. A considerable slowdown of the migration rate may be anticipated. Ra-226 was chosen for analysis because of its relatively low adsorption and lowest allowable activity in drinking water among all radioisotopes (ICRP 1959). The distribution coefficient for Th-230 was not determined from a laboratory measurement, but studies at other mines showed that it is usually very high, with a value of 50,000 $cm^3/g$ at pH = 7 (Rancon 1973; Sears et al. 1975). The lower value chosen in the analysis (1000 $cm^3/g$) gives more conservative results. Th-230 was selected because of its relatively high distribution coefficient and low dissolution rate so that a wide range of radionuclides could be covered in the problem. The radioactive decay constants for these two species are $4.32 \times 10^{-4}$ $yr^{-1}$ and $8.46 \times 10^{-6}$ $yr^{-1}$. The width of the Jackpile sandstone, which was considered to be the source of the radionuclides released to the groundwater, was estimated to be about 1000 m (3300 ft). Therefore, $y_1$ and $y_2$ in Figure C.1 were taken as 500 m each. A list of input data for groundwater migration analysis is given in Table C.2.

Table C.2. Input Data for Analysis of Radionuclide Migration in the Groundwater at Jackpile-Paguate Mines

| Parameter | Value |
|---|---|
| Distance between Jackpile Pit and Laguna | 10 km |
| Hydraulic conductivity of sandstone | 0.12 m/day |
| Unidirectional (north-south) groundwater velocity | 1.87 m/yr |
| Piezometric head at the Jackpile Pit | 1817 m |
| Piezometric head at Laguna | 1752 m |
| Porosity | 0.15 |
| Longitudinal dispersivity | 2 m |
| Transversal dispersivity | 0.5 m |
| Distribution coefficient | |
| Ra-226 | 100 $cm^3/g$ |
| Th-230 | 1000 $cm^3/g$ |
| pH | 7 |
| Radioactive decay constant | |
| Ra-226 | $4.32 \times 10^{-4}$ $yr^{-1}$ |
| Th-230 | $8.46 \times 10^{-6}$ $yr^{-1}$ |
| Width of Jackpile Pit | 1000 m |
| Soil bulk density | 1 $g/cm^3$ |

### C.2.5 Results

Two cases of the migration of the two species of interest (Ra-226 and Th-230) released from the site of the Jackpile pit were investigated. In the first case, both species were assumed to behave like conservative ions (i.e., $R_d = 1$). In the second case, the species were assumed to follow their normal behavior pattern and interact with the soil matrix. Isopleths for a range of normalized concentrations ($10^{-5} \leq C/C_o \leq 0.5$) for Ra-226 for a time span of 5000 and 10,000 years under the assumption that $R_d$ equals one are shown in Figures C.2 and C.3, respectively. In this case, the computed concentrations at Laguna were about $10^{-5}$ and $10^{-1}$ times the source concentration for the next 5000 and 10,000 years, respectively. The isopleths for the same range of $C/C_o$ of Ra-226 for a time span of 1,000,000 years and with the retardation factor taken into account are shown in Figure C.4. In this instance, the tip of the plume corresponding to $C/C_o$ of $10^{-5}$ seems to have migrated only 2000 meters from the Jackpile pit.

The isopleths for the same range of $C/C_o$ for Th-230 at 5000 and 10,000 years (with $R_d = 1$) are shown in Figures C.5 and C.6, respectively. The migration rate is much greater than that in the case of Ra-226; this due to the longer half-life of Th-230 (i.e., half-life of 80,000 years for Th-230 vs. 1600 years for Ra-226). However, when adsorption is factored into the calculations, the tip of the plume corresponding to $C/C_o = 10^{-5}$ apparently has migrated only 200 meters from the source after 1,000,000 years (Fig. C.7). This is indicative of the relatively high distribution coefficient of this radionuclide.

Based on these calculations, it is concluded that the potential impact of radionuclides released from the site of the Jackpile pit does not seem likely to threaten the quality of groundwater at the town of Laguna.

## C.3 CROSS-SECTION FLOW ANALYSIS FOR THE BLOCKED ARROYO

The influence of rainfall and of ponded water on the groundwater table at the site of the block arroyo was obtained through the solution of Boussinesq's equation, written as:

$$\frac{\partial}{\partial x} \left(KY \frac{\partial Y}{\partial x}\right) + q\ (t) = S_y\ (x,\ t) \frac{\partial Y}{\partial t}\ , \qquad (C.3\text{-}1)$$

where:

$Y$ = elevation of the phreatic surface measured from the quasi-impermeable base (L)

$S_y\ (x, t)$ = specified yield ($L^o$), where $S_y = n - \theta_r$

$n$ = porosity

$\theta_r$ = residual water content ($L^o$)

$K$ = the hydraulic conductivity ($LT^{-1}$), and

$q(t)$ = is the rainfall rate ($LT^{-1}$).

Derivation of the governing groundwater flow equation (Eq. C.3-1) is under Dupuit assumptions (Murray and Monkmeyer 1973). To render Eq. C.3-1 amenable to the solution of the problem, the lower formation, composed of Dakota and Jackpile sandstone (Fig. 5.1 in Sec. 5), was conservatively assumed to be impervious to percolation of water from the upper soil formation because of its very low hydraulic conductivity ($K = 1.216 \times 10^{-3}$ m/day). The formation underlying the waste pile was assumed to be composed of alluvium with an average thickness of 3 m (10 ft) and with hydraulic conductivity conservatively assumed to be 30.0 m/day (98.5 ft/day). The hydraulic conductivity of the waste pile was assumed to be 57.9 m/day (190 ft/day).

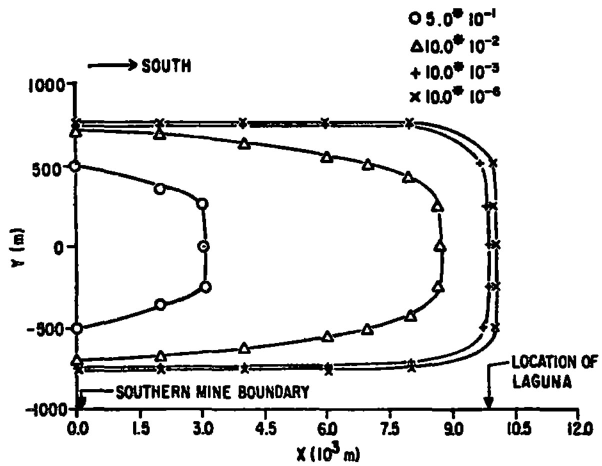


Figure C.2. Normalized Concentration of Ra-226 at 5000 Years. (Retardation factor = 1)

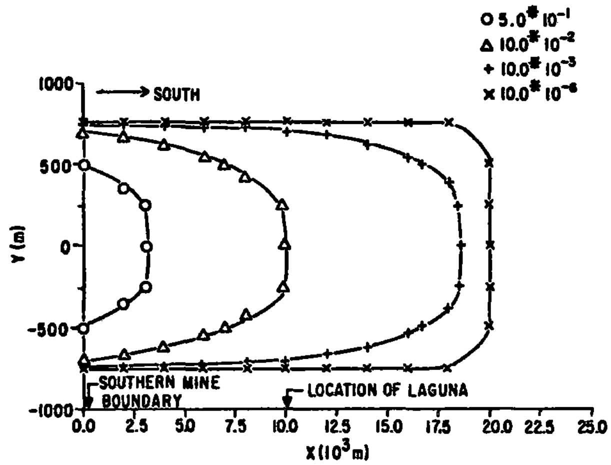


Figure C.3. Normalized Concentration of Ra-226 at 10,000 Years. (Retardation factor = 1)

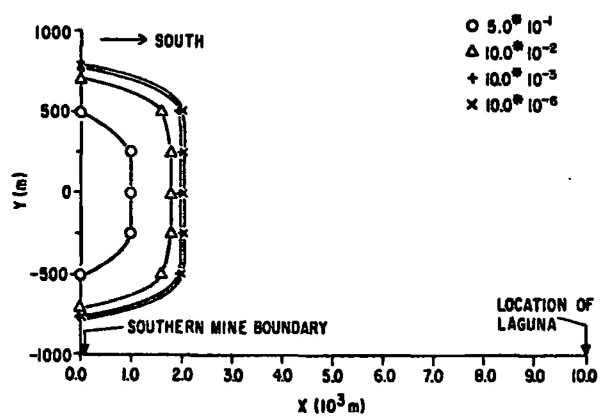


Figure C.4. Normalized Concentration of Ra-226 at 10,000,000 Years. (Retardation factor ≠ 1)

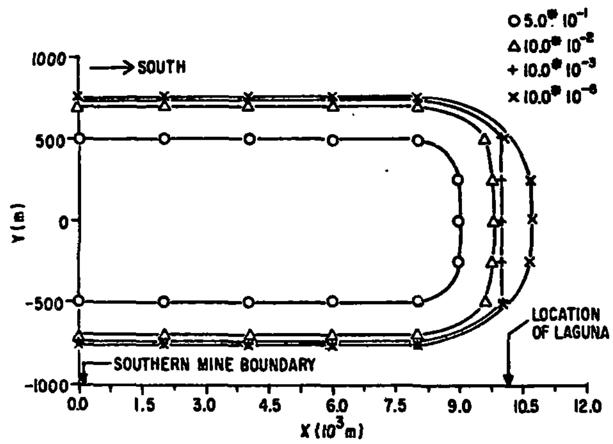


Figure C.5. Normalized Concentration of Th-230 at 5000 Years. (Retardation factor = 1)

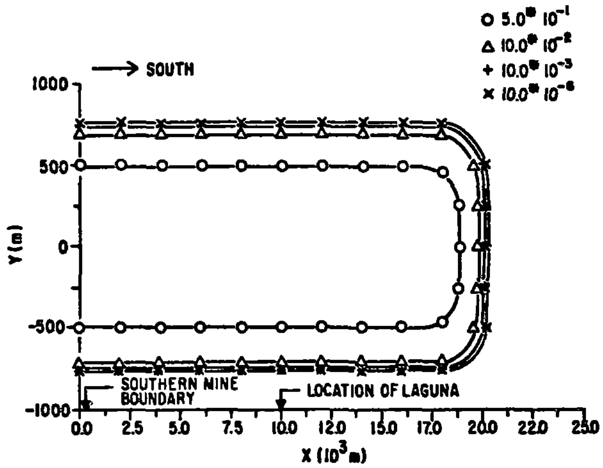


Figure C.6. Normalized Concentration of Th-230 at 10,000 Years. (Retardation factor = 1)

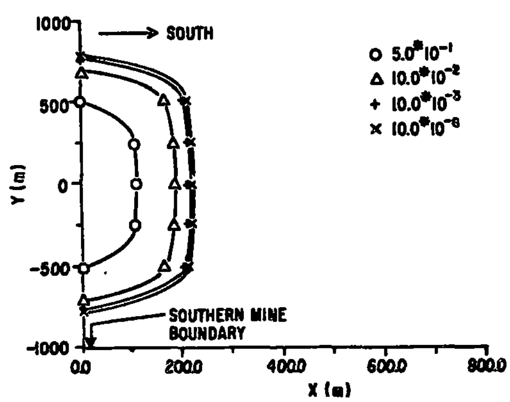


Figure C.7. Normalized Concentration of Th-230 at 10,000,000 Years. (Retardation factor ≠ 1)

The following boundary conditions and input parameters were assumed:

a) Evaporation greatly exceeds rainfall in the region [i.e., average effective rainfall (rainfall minus infiltration) of about 2.5 cm/month (1 in/month) compared to average evaporation of about 15 cm/month (6 in/ month)]. Three scenarios of intermittent effective rainfall corresponding to 2.5 cm/month (1 in/month) were assumed as shown in Figure C.8.

b) There would be a constant head of 0.6 m (2 ft) of water 50 m (165 ft) in diameter during rainfall and drying subsequent to precipitation.

The specific yield was obtained from:

$$S_y = n - \theta_r = 0.2 - 0.18 = 0.02 .$$

Resulting fluctuations in the groundwter table over a simulation time of one year corresponding to the three cases of rainfall pattern are shown in Figures C.9, C.10, and C.11. Recharge mounds as shown in these figures would be expected to occur above the relatively impervious Dakota and Jackpile sandstones due to percolation through the zone of aeration if the volume of seepage discharge was substantial.

In all cases, results seem to indicate that the water would spread horizontally and would be in direct contact with the waste pile only a short distance from the pond. Of the three scenarios of rainfall pattern, Case 3 seems to be more realistic, although it still is on the conservative side. Even for this case, the highest groundwater level would still about 0.5 m (1.6 ft) below the bottom of the waste pile (Fig. 5.5). Based on this analysis, the potential for contamination of groundwater by infiltration of ponded water or percolation of rainfall through wastes is minimal.

## C.4 GROUNDWATER-FLOW ANALYSIS FOR SOUTH PAGUATE AND JACKPILE PITS

In this appendix, the flow equations used to estimate the equilibrium groundwater levels in the South Paguate and Jackpile pits, the selection of data values for various parameters required for computation, and the calculational procedures are presented.

The flow sections selected for groundwater-flow analysis in the South Pauate and Jackpile pits are shown in Figure C.12. The section through South Paguate pit is from the southernmost edge of the pit (southeast of well P6) to the Rio Paguate upstream from well P4. The section through the Jackpile pit is from the western edge of Gavilan mesa, through well site M18, to the Rio Paguate. These sections represent the most likely paths for groundwater flow in each area. Schematic diagrams showing the cross section of the selected flow paths are shown in Figure C.13 for South Paguate pit and in Figure C.14 for Jackpile pit. Comparison of the two cross sections indicates that the hydrogeologic characteristics of these two areas are somewhat different. Discharge from pit backfill will be to the Rio Paguate at the South Paguate pit, and to the Jackpile sandstone - alluvium - Rio Paguate at the Jackpile pit. However, even with these differences, the flow equations used to predict the equilibrium groundwater levels in the two pits are basically the same. This is described below.

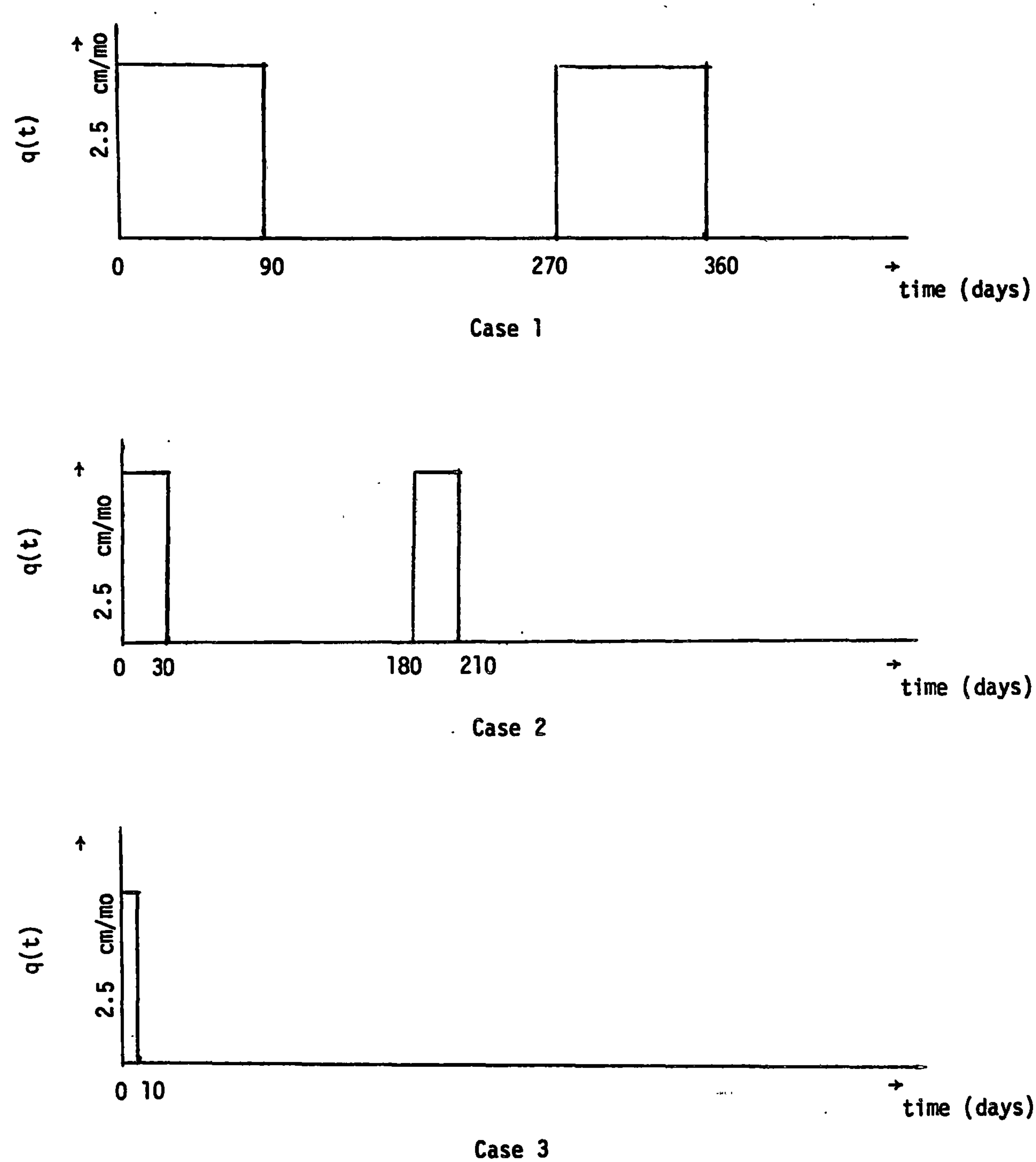


Figure C.8. Three Cases of Intermittent Effective Rainfall.

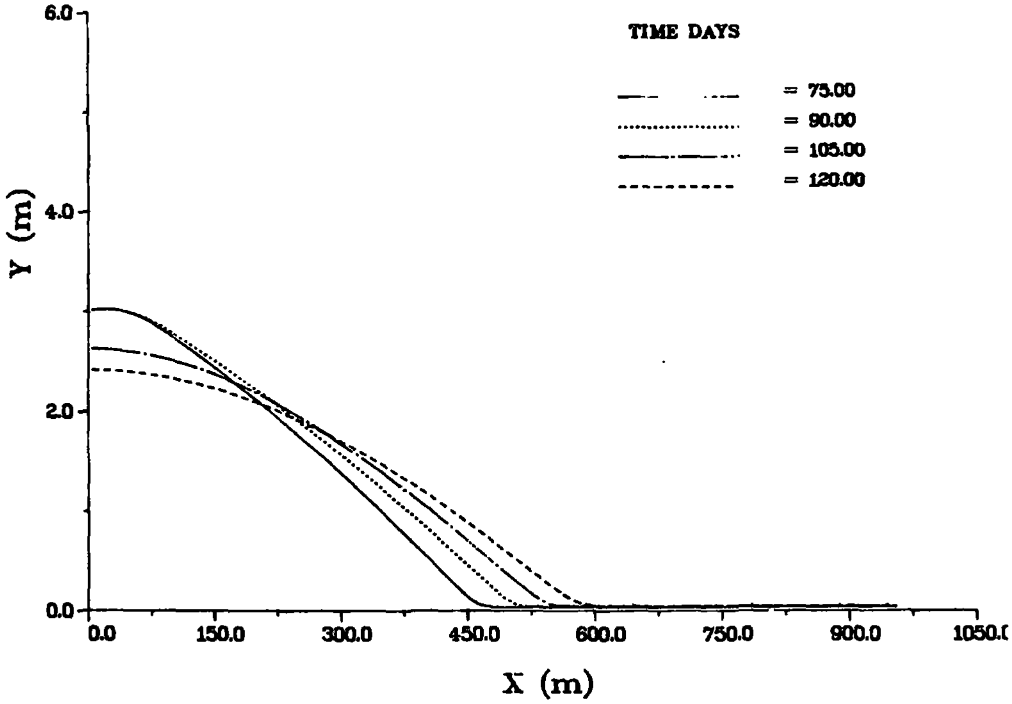


Figure C.9(a). Groundwater-Table Fluctuations under Rainfall Case #1--Days 75-120.

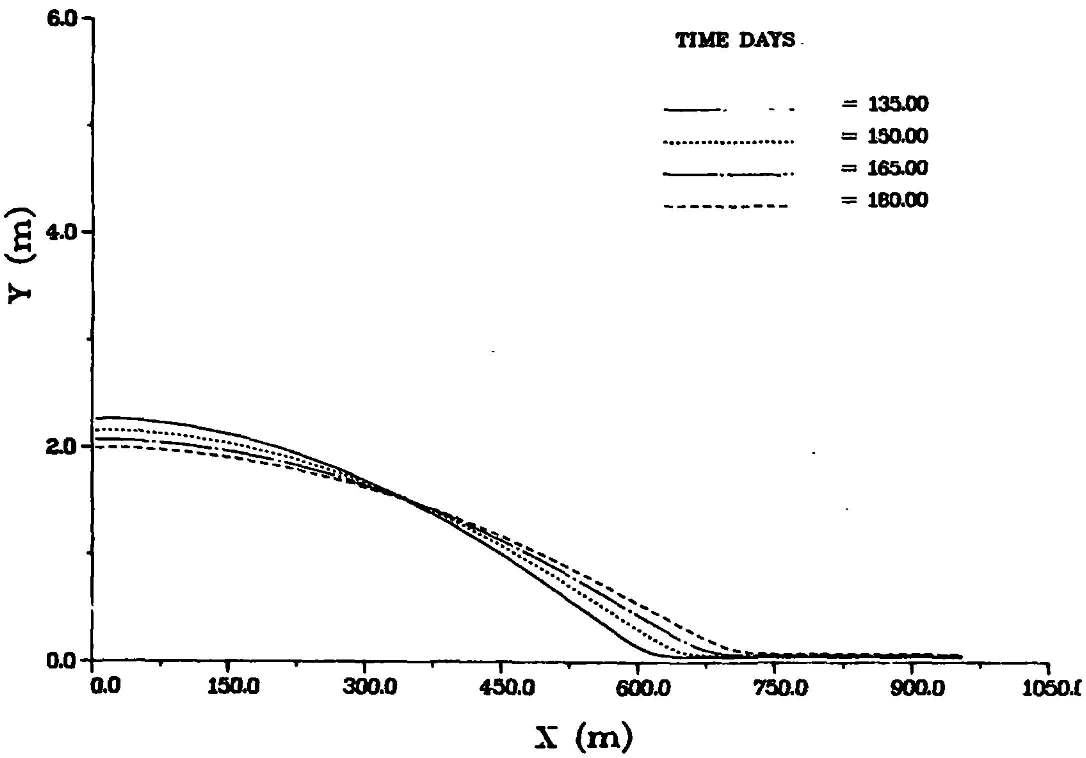


Figure C.9(b). Case #1--Days 135-180.

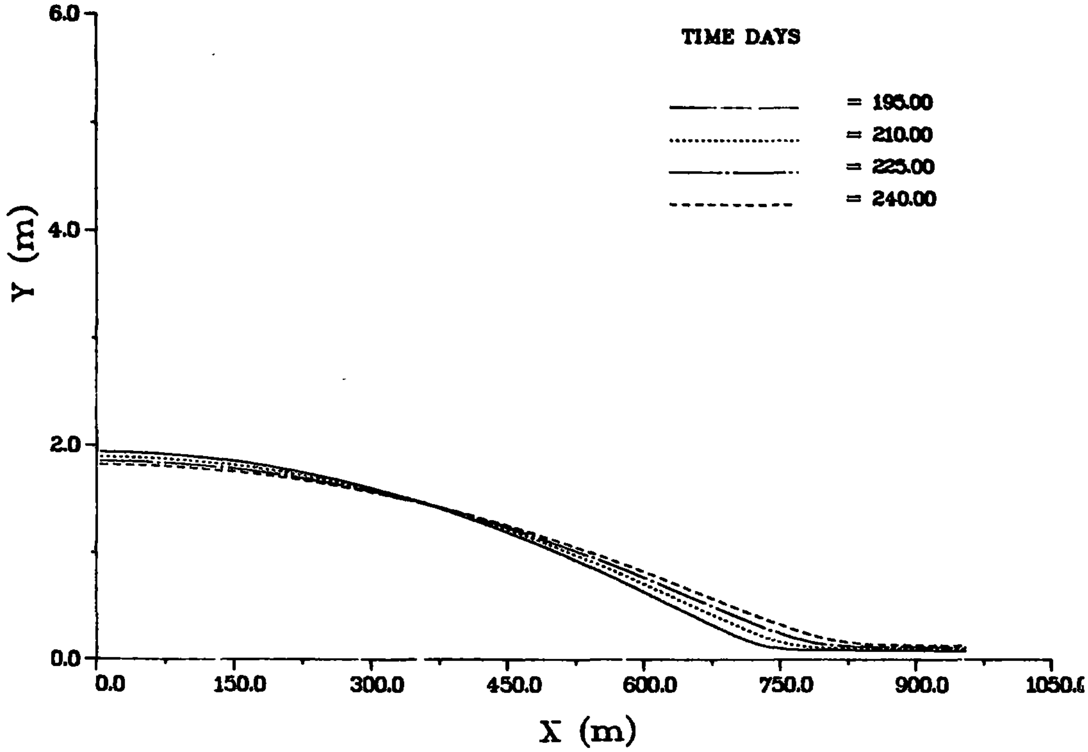


Figure C.9(c). Case #1--Days 195-240.

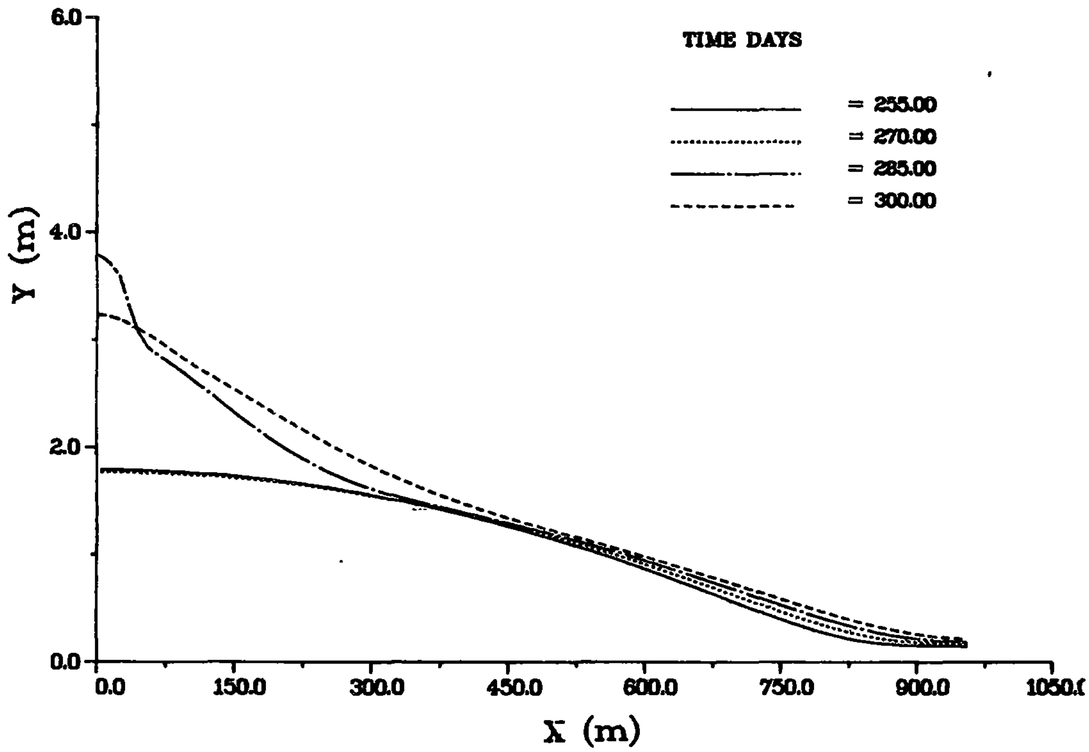


Figure C.9(d). Case #1--Days 255-300.

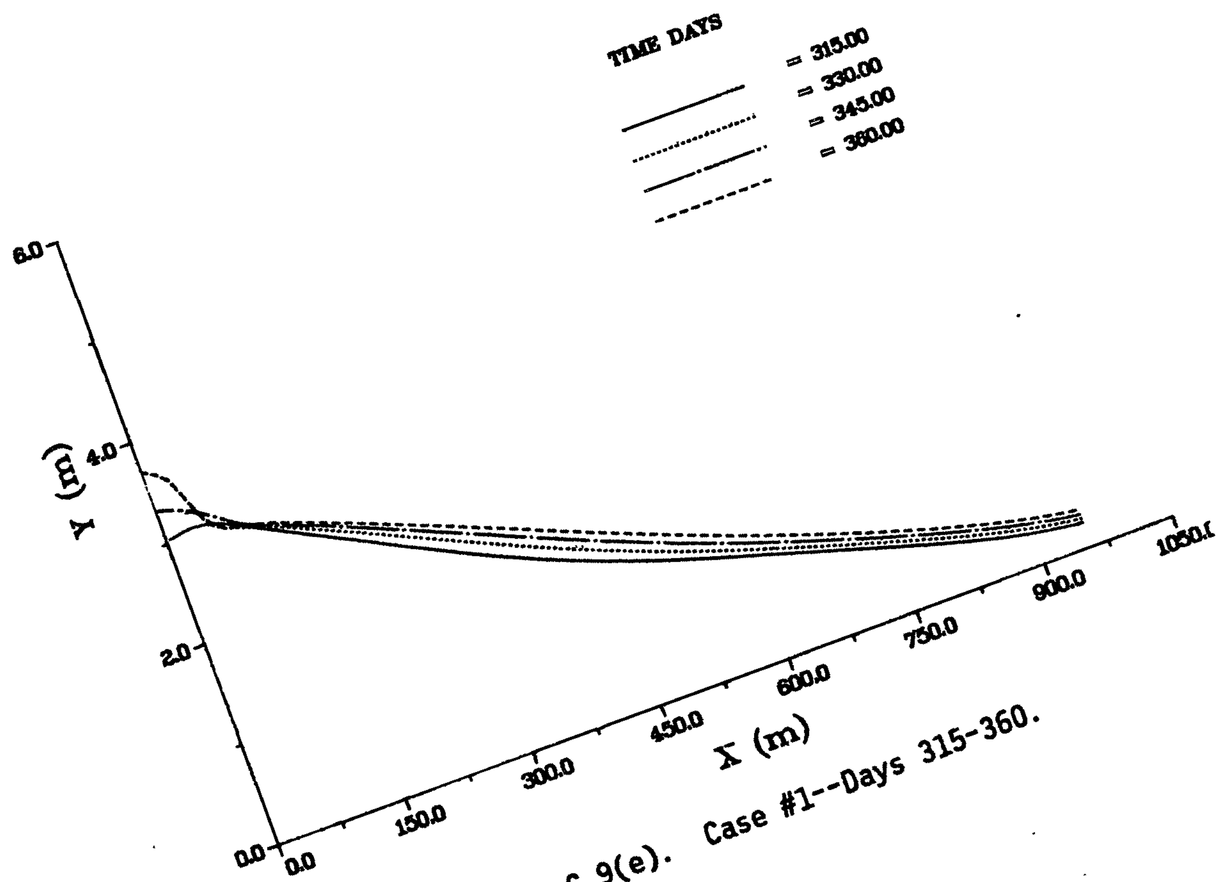


Figure C.9(e). Case #1--Days 315-360.

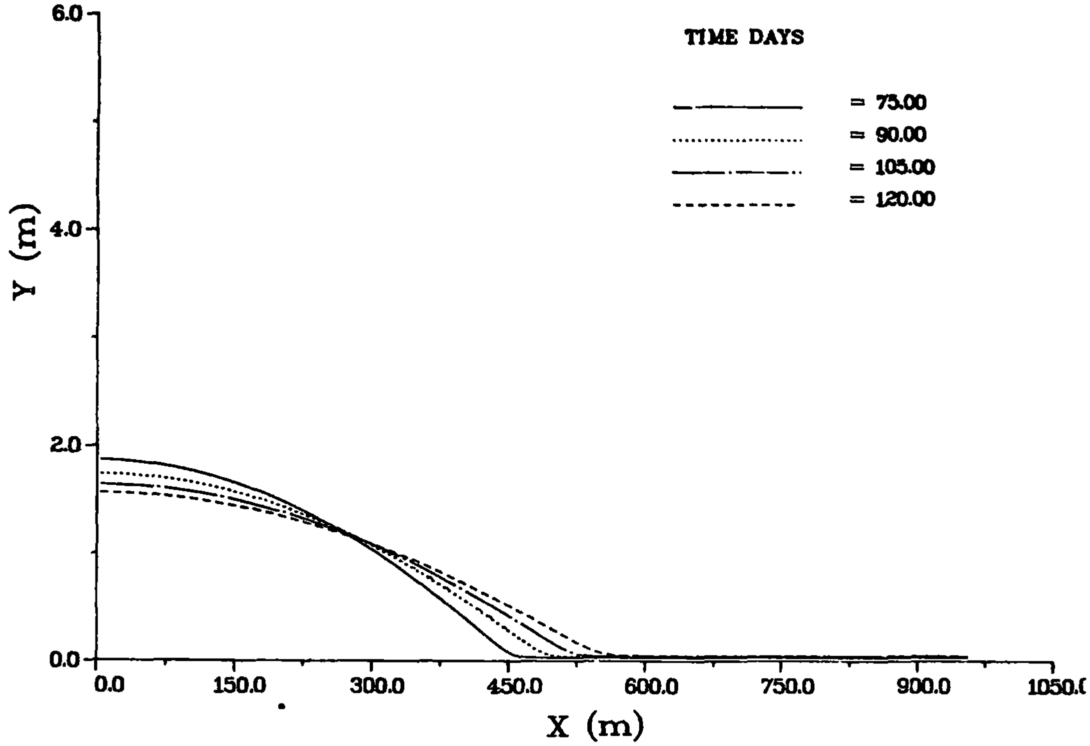


Figure C.10(a). Groundwater-Table Fluctuations under Rainfall Case #2--Days 75-120.

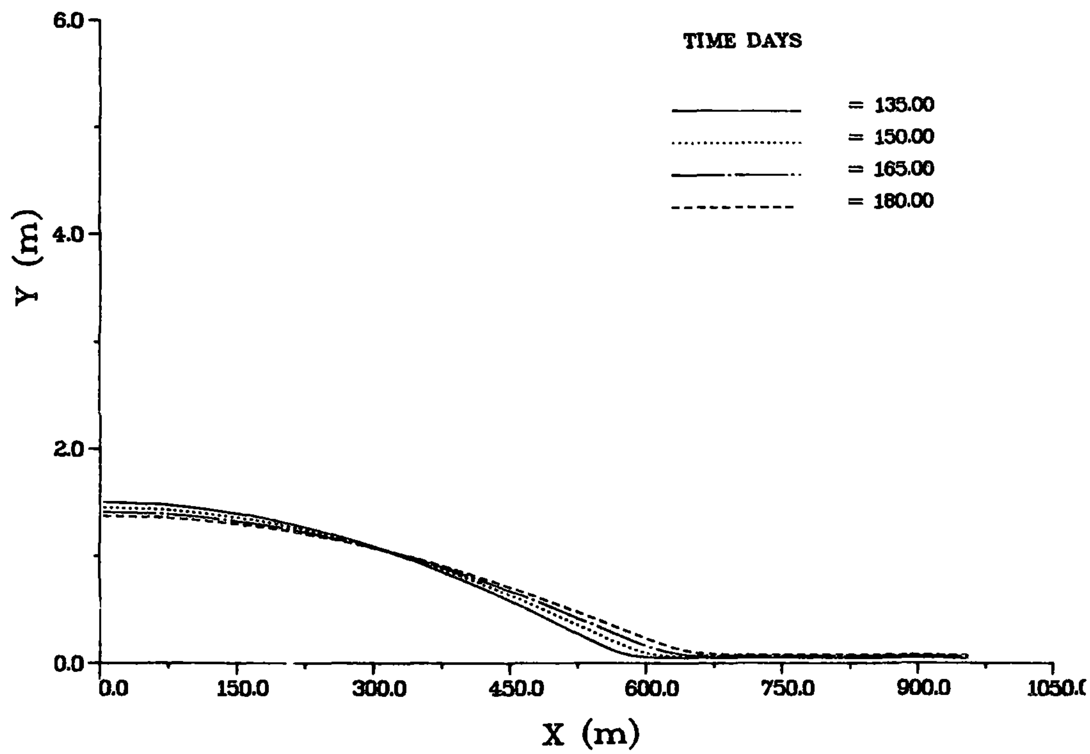


Figure C.10(b). Case #2--Days 135-180.

C-20

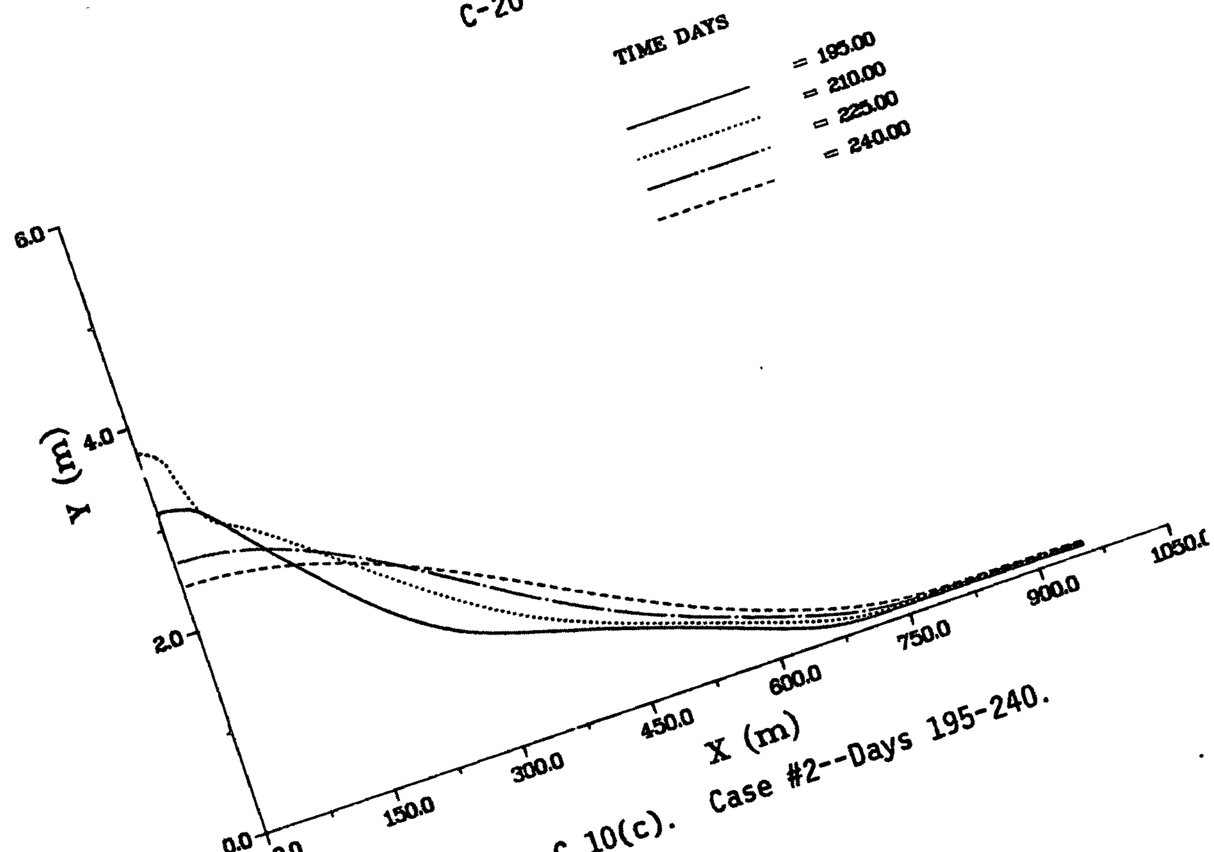


Figure C.10(c). Case #2--Days 195-240.

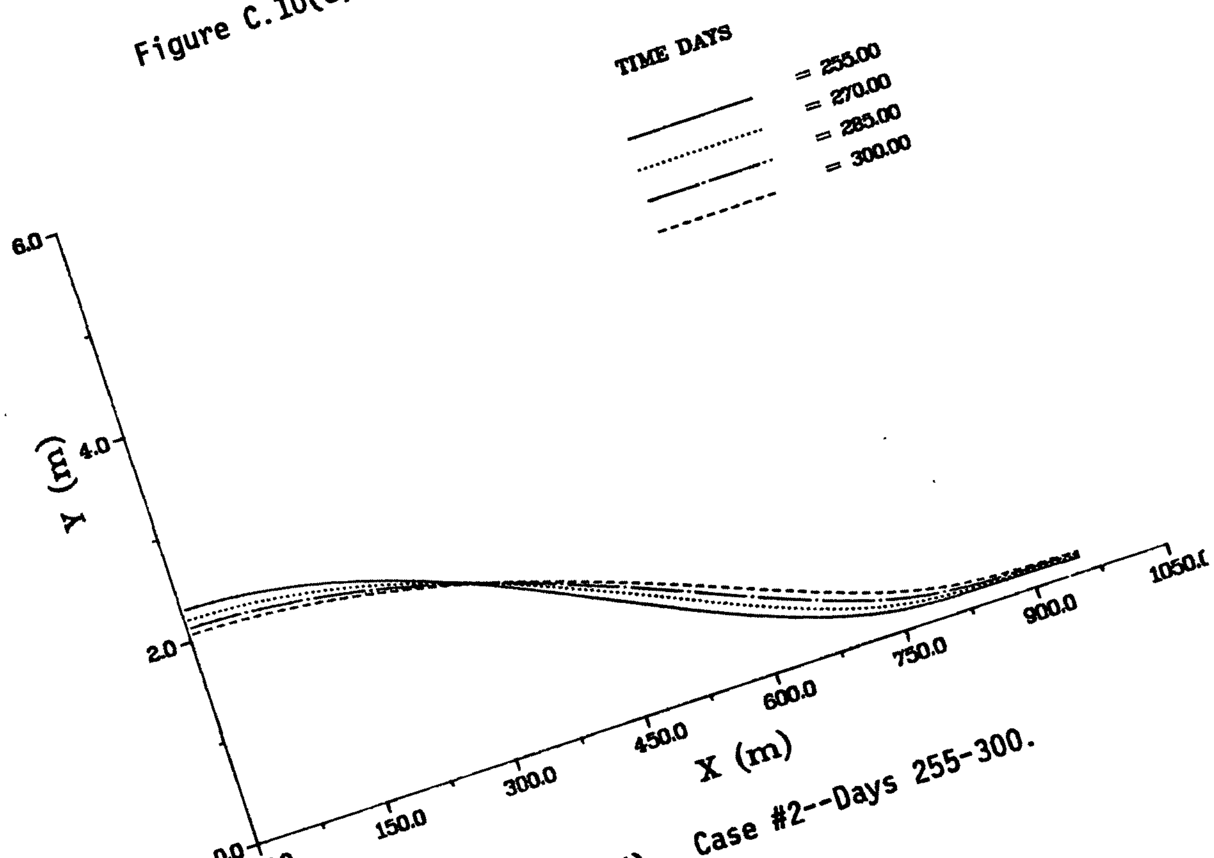


Figure C.10(d). Case #2--Days 255-300.

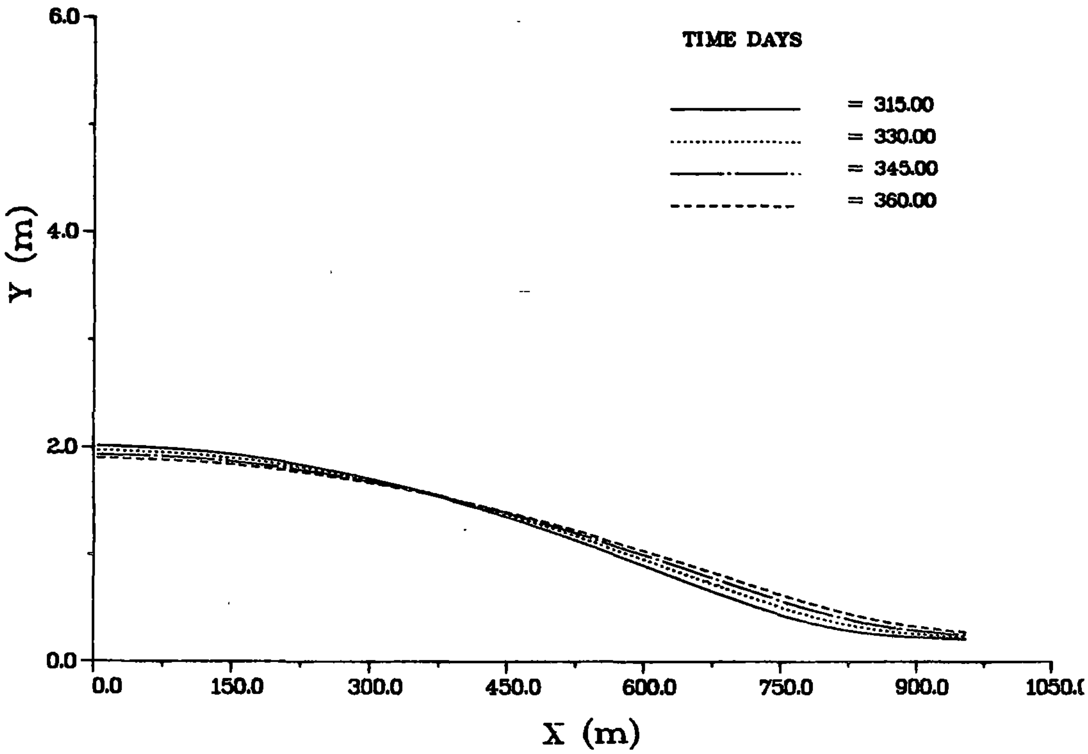


Figure C.10(e). Case #2--Days 315-360.

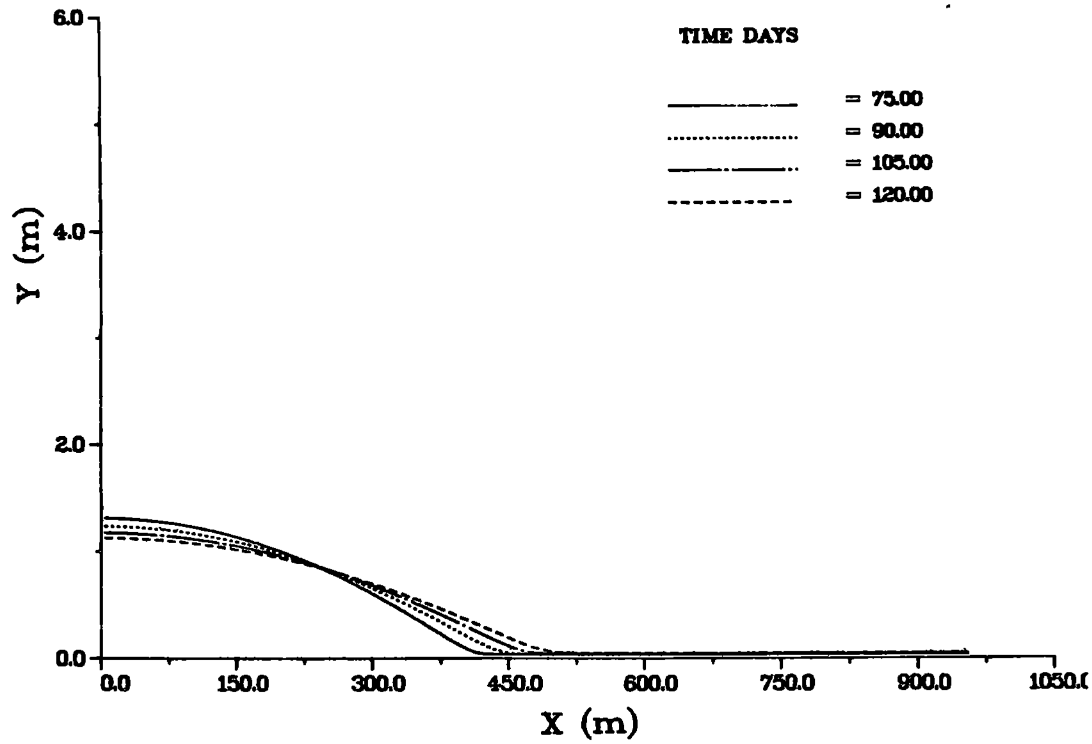


Figure C.11(a). Groundwater-Table Fluctuations under Rainfall Case #3--Days 75-120.

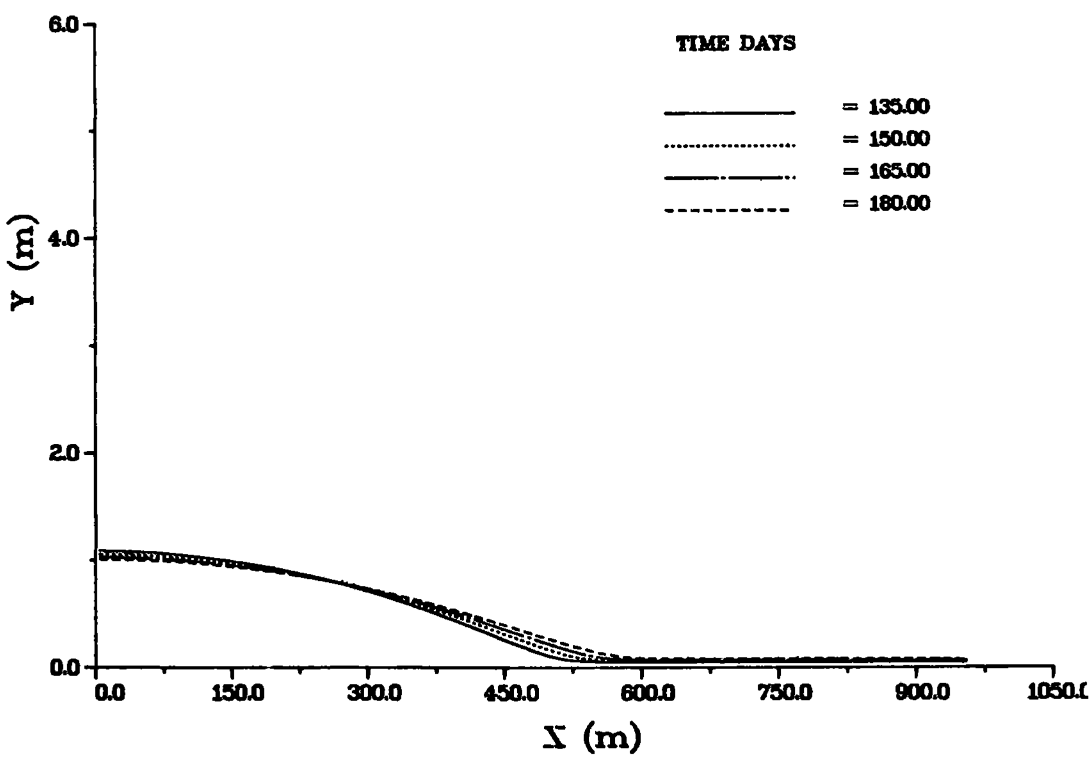


Figure C.11(b). Case #3--Days 135-180.

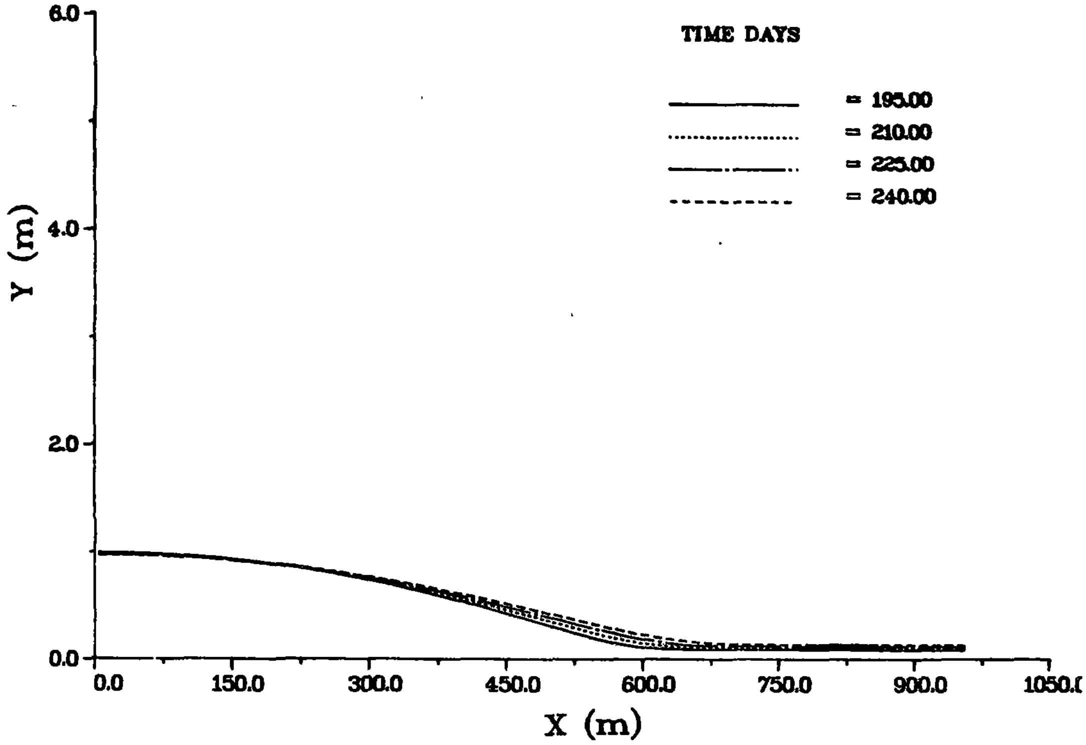


Figure C.11(c). Case #3--Days 195-240.

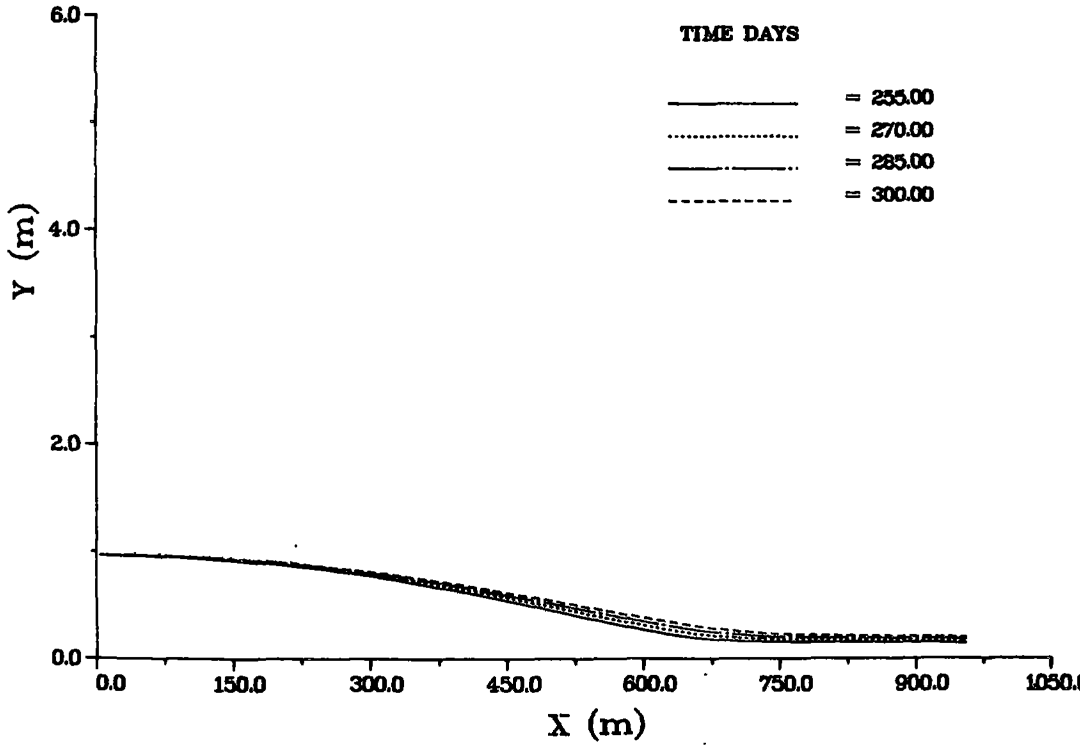


Figure C.11(d). Case #3--Days 255-300.

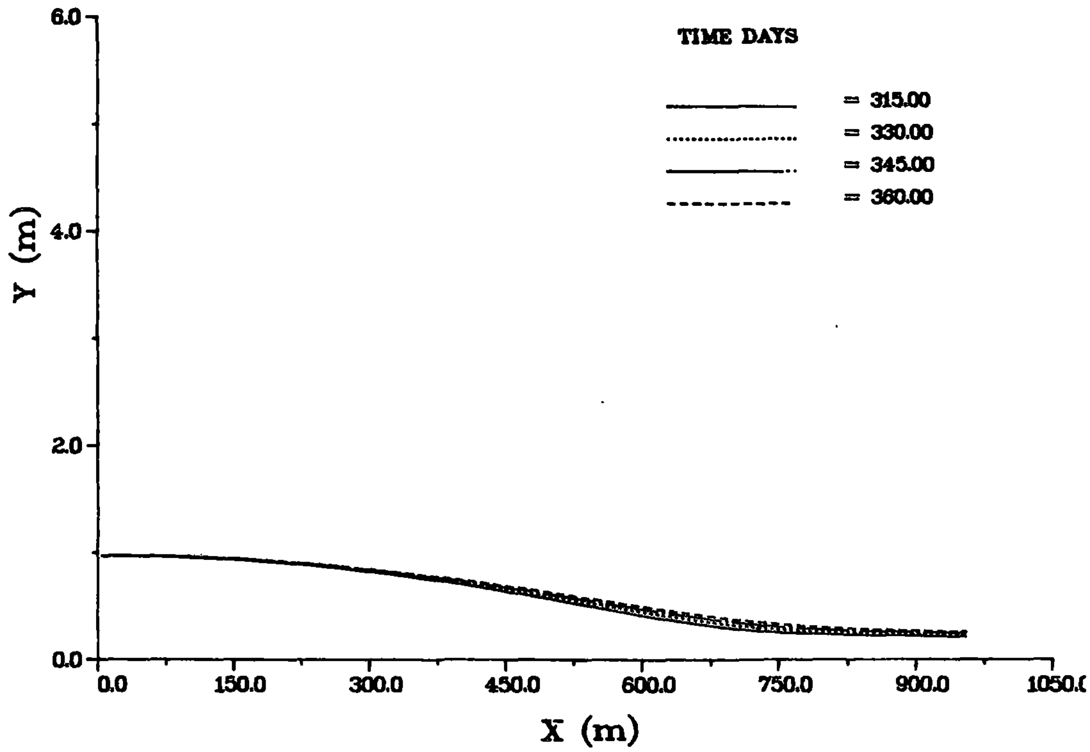


Figure C.11(e). Case #3--Days 315-360.

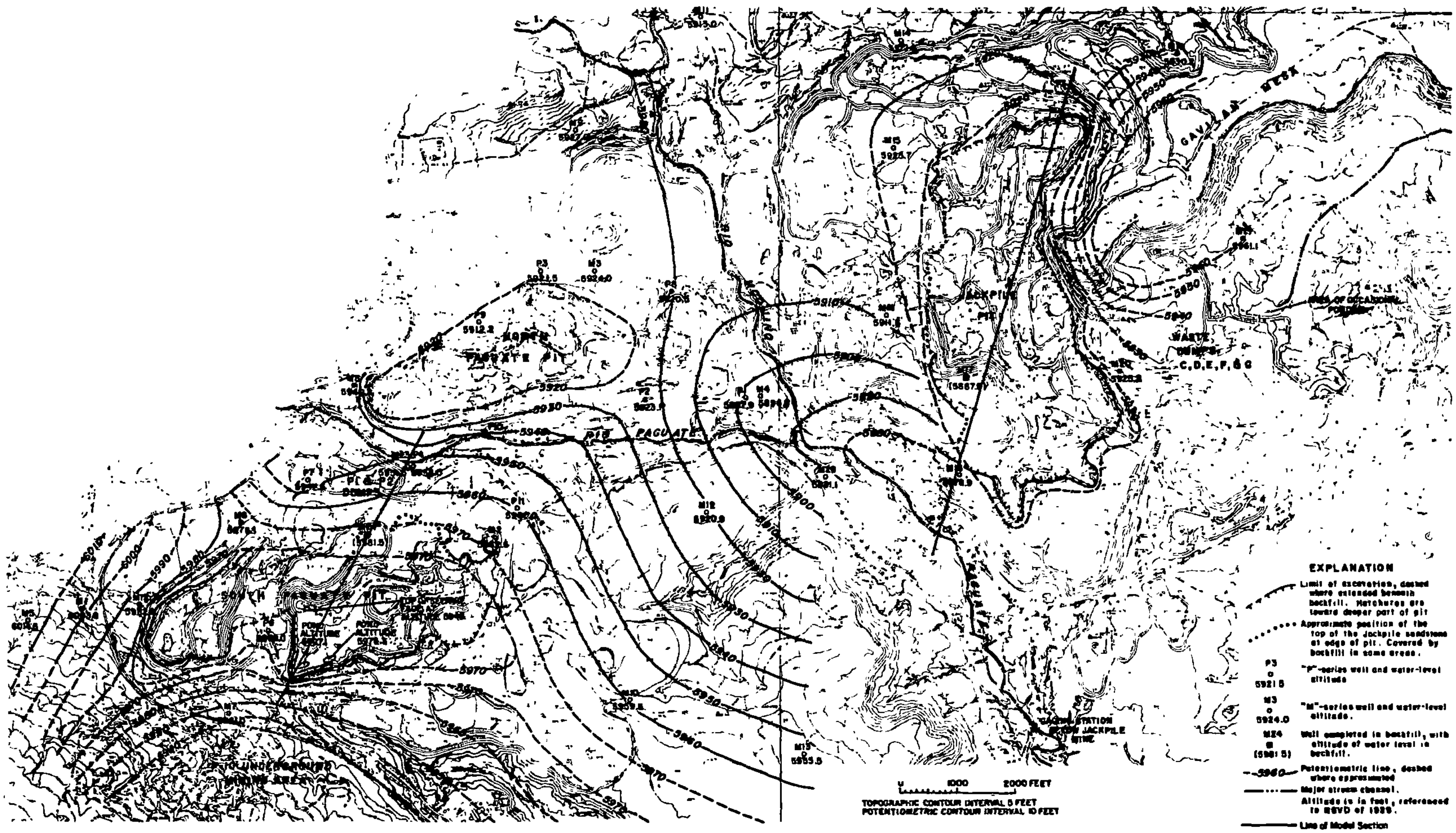


Figure C.12. Topographic and Hydrologic Map of the Jackpile-Paguate Mine Area.

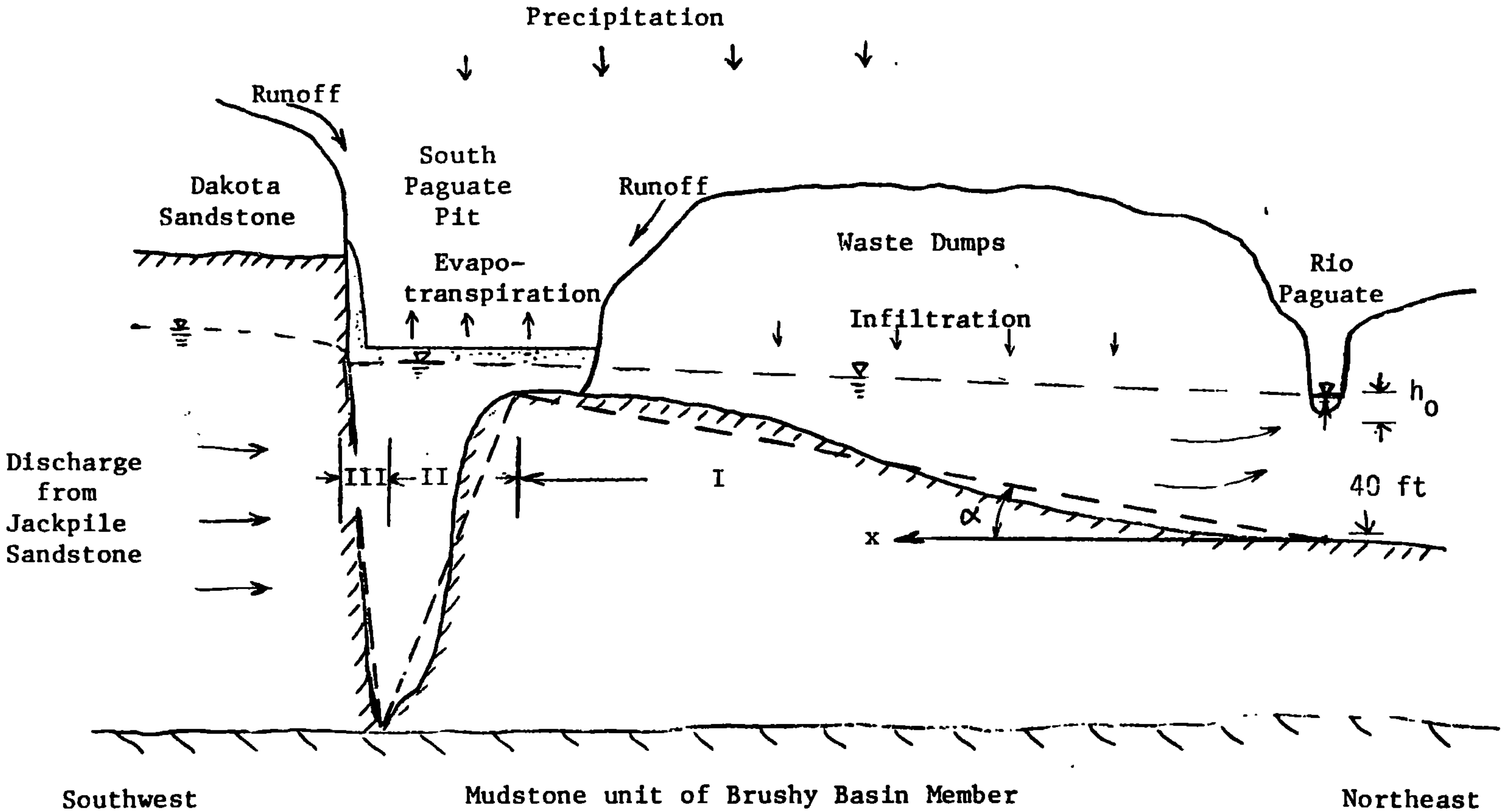


Figure C.13. Schematic Diagram Showing the Cross Section of Selected Groundwater Flowpath through the South Paguate Pit.

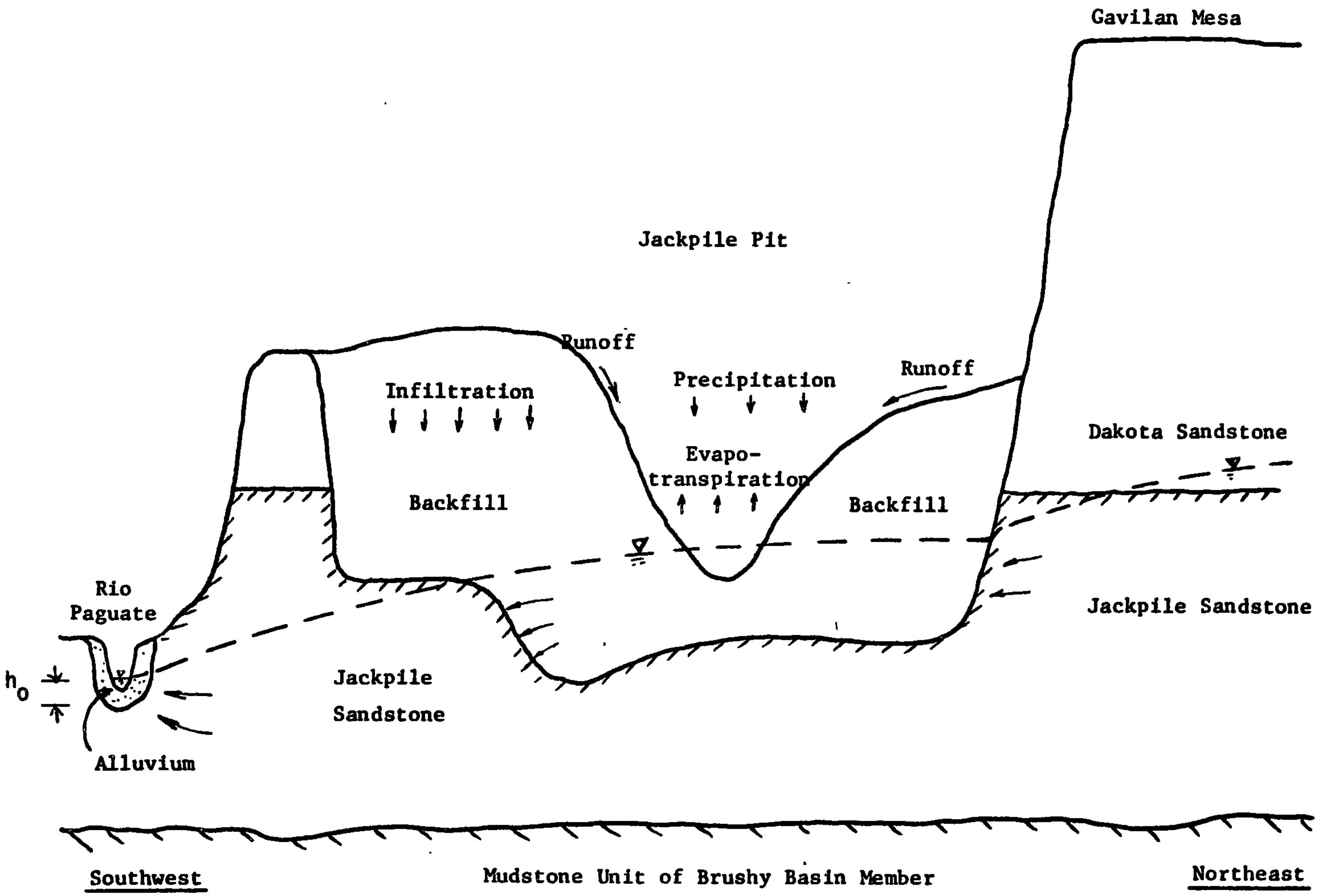


Figure C.14. Schematic Diagram Showing the Cross Section of Selected Groundwater Flowpath through the Jackpile Pit.

### C.4.1 Groundwater Flow Equations

The groundwater levels in the South Paguate and Jackpile pit fills were estimated by using the Dupuit theory for unconfined flow. (In this type of flow, one boundary of the flow domain is a free surface.) The Dupuit theory is based on two basic assumptions--(1) the stream lines can be taken as horizontal for small inclinations of the line of seepage, and (2) the hydraulic gradient is equal to the slope of the free surface and is invariant with depth (Polubarinova-Kochina 1962). These assumptions were assumed valid for the present study.

Based on the Dupuit theory, two-dimensional equations describing the groundwater flow on both a horizontal and an inclined lower impervious boundary have been developed (Polubarinova-Kochina 1962; Harr 1962). The use of these equations for each pit is described below.

The schematic diagram shown in Figure C.13 indicates that the approximate position of the Jackpile sandstone surface in the South Paguate pit area slopes gently about half a degree from the pit to the Rio Paguate. The Jackpile sandstone is also relatively impermeable compared to the overlying backfill materials. Any discharge into the backfill would tend to flow to the Rio Paguate with very little leakage into the underlying sandstone. Because of these hydrogeologic characteristics, the Dupuit equation for the case with an inclined lower impervious boundary was used to determine the groundwater levels in the South Paguate pit area. The general format of this equation can be written (based on Polubarintova-Kochina 1962; Harr 1962) as:

$$h - x \tan \alpha + \frac{q}{K_b \tan \alpha} = B \exp \frac{K_b h \tan \alpha}{q} , \qquad \text{(C.4-1)}$$

where x is the horizontal coordinate; h is the elevation of the free surface measured from the horizontal axis; $\alpha$ is the angle of inclination of the impervious boundary; q is the discharge per unit width through any vertical section in the backfill; $K_b$ is the hydraulic conductivity of the backfill; and B is an integration constant that depends on the boundary conditions at the hydraulic control locations.

The mining operations in the South Paguate pit area have greatly altered the level of the groundwater surface from pre-mining conditions. There is no information available to determine what the appropriate boundary conditions will be after the groundwater system in the area reaches equilibrium. For the present study, the hydraulic control location for Eq. C.4-1 was set at the maximum possible water level ($h_o$) in the Rio Paguate, which was assumed to be a gaining stream along its length from the town of Paguate to its confluence with the Rio Moquino. This assumption would give conservative results since any decrease in groundwater level at Rio Paguate would lower the equilibrium groundwater level in the upstream area.

As it was mentioned previously, the positions of the Jackpile sandstone surface, as shown in Figure C.13, are only approximate--the exact elevation of the bedrock surface is not known. Therefore, the equilibrium groundwater level at the South Paguate pit was also calculated by using the Dupuit's formula for two-dimensional flow on a horizontal impervious boundary, i.e., $\alpha = 0°$. In this case, the flow equation can be written (Polubarinova-Kochina 1962; Harr 1962) as:

$$q = K_b \frac{h^2 - h_o^2}{2L} \quad , \qquad \text{(C.4-2)}$$

where $h_o$ represents the water elevation at the hydraulic control point and L is the horizontal distance between h and $h_o$. The results obtained from both Eqs. C.4-1 and C.4-2 are used to evaluate the effects of sloping bedrock surface on the equilibrium groundwater level.

The schematic diagram shown in Figure C.14 indicates that the existing backfill in the Jackpile pit overlies the Jackpile sandstone, which in turn is underlain by a mudstone unit of the Brushy Basin Member. The mudstone is composed of fine silt-sized fragments and was assumed to be the lower hydrologic boundary in the local groundwater system. Discharge from Jackpile pit backfill would be through the Jackpile sandstone. Most of the water would then enter the alluvium and the Rio Paguate southwest of the pit, with some flowing through the mudstone unit of the Brushy Basin member. The level of the Rio Paguate ($h_o$) would therefore be the ultimate hydraulic control for water levels in the Jackpile pit area.

The groundwater levels in the Jackpile pit area were estimated by using Eq. C.4-2 instead of a sophisticated numerical model because of the lack of field data for such parameters as exact positions of the saturated zones, the hydraulic gradients, and the bedrock hydraulic conductivity. A computer program was written to solve the equation. The solutions were obtained by trial and error, mainly because discharge from bedrock upstream of the Jackpile pit was not known precisely and had to be estimated. For an assumed discharge, the groundwater level at the upstream recharge area can be back-calculated from the stream control level in Rio Paguate. The calculated groundwater level would have to have a hydraulic gradient that would yield a discharge about the same as the initially assumed value.

## C.4.2 Evaluation of Parameters

### C.4.2.1 South Paguate Pit

The groundwater surfaces in the South Paguate pit were determined principally by the recharge to the pit and discharge to the Rio Paguate. The recharge to the pit includes the discharge from the Jackpile sandstone and local infiltration from direct precipitation and runoff. The amount of infiltration is determined by several parameters, including precipitation, surface runoff, and evapotranspiration. Values for most of these parameters can be reasonably estimated. However, little data are available regarding evapotranspiration. The average evapotranspiration for the entire Rio Paguate drainage basin would be about 98% of precipitation, but this value could be quite different locally, particularly where direct precipitation and runoff from steep pit walls may quickly infiltrate permeable backfill.

Because of the uncertainties concerning infiltration, the calculations of equilibrium groundwater levels were conducted for the following three infiltration values: (1) no infiltration, (2) 5% of local precipitation infiltrates, and (3) 10% of local precipitation infiltrates. These assumed infiltration values are considered to be conservatively high because of the extremely high evapotranspiration in the region. The infiltration study performed by Oztunali et al. (1981), incorprating the water-balance method introduced by Thornthwaite and Mather (1964), indicated that the infiltration rate in the southwestern part of the United States is practically zero.

The average annual precipitation of 24.1 cm (9.5 in) was used in these calculations. The drainage area into the South Paguate pit is about $1.6 \times 10^6$ $m^2$ (400 acres). Based on the annual average rainfall data and the worst-case assumption that there would be no evapotranspiration, the volume of water collected in the pit would be about $3.9 \times 10^5$ $m^3$ (320 ac-ft) per year.

Discharge per unit width from the Jackpile sandstone into the South Paguate pit ($q_j$) was calculated by use of the Darcy's equation:

$$q_j = K_j \, I_j \, B_j \; , \qquad \text{(C.4-3)}$$

where $I_j$ is the equilibrium hydraulic gradient, $K_j$ is the hydraulic conductivity, and $B_j$ is the saturated thickness, all for Jackpile sandstone. The discharge would be from the west and south of the pit, along a length of about 2440 m (8000 ft). The hydraulic gradient ($I_j$) in the Jackpile sandstone was taken from the value measured at wells M1 and M5 (Fig. C.12), which was about 0.02 (Zehner 1982). It was assumed that this gradient would be unchanged when the groundwater eventually recovers to its equilibrium level. Hydraulic conductivity ($K_j$) of the Jackpile sandstone is about 0.09 m/day (0.3 ft/day) (Zehner 1982). Saturated thickness of the Jackpile sandstone ranges from 29 to 43 m (95 to 140 ft) at wells M5, M1, and 6, so 37 m (120 ft) was used as an average. Based upon these data and Eq. C.4-3, the bedrock discharge into the pit would be about 163 $m^3$/day (5760 $ft^3$/day). Since the bottom of the bedrock is about at the bottom of the pit, the bedrock discharge and the rainfall infiltration at Rio Paguate were assumed constant and were used for the entire flow field. This assumption would give conservative results since the groundwater discharge would actually increase from 163 $m^3$/day (5760 $ft^3$/day) at the southern end of the pit to the maximum combined total flow at the stream with the addition of infiltrated precipitation.

The backfill material in the pit is considerably more permeable than the underlying bedrock. The K-value of backfill has been estimated as about 58 m/day (190 ft/day) (Hydro-Search 1981). Flow through the 488-m (1600-ft) length of backfill along the stream was assumed to be through the entire 12-m (40-ft) thickness of backfill beneath the streambed (Fig. C.14). The downstream control flow depth ($h_o$) was assumed to be either 0, 0.6, or 1.5 m (0, 2, or 5 ft), depending upon the water level in the Rio Paguate. The flow area in the backfill, as shown in Figure C.13, was divided into three different regions for different angles of inclination, and Eq. C.4-1 was applied to each region to calculate the ultimate recovery levels of groundwater.

The angles of inclination for the bedrock surface were measured as about 0.5, 6.4, and 42.0 degrees for regions I, II, and III, respectively. The horizontal distances for the three regions were measured as about 910, 550 and 210 m (3000, 1800, and 700 ft). The case of a horizontal impervious boundary also was considered.

### C.4.2.2 Jackpile Pit

Eq. C.4-3 was used to calculate discharge from the Jackpile sandstone into the Jackpile pit. Groundwater data from pumping tests of selected test wells indicated that recharge flow into the Jackpile mine area would probably be from overlying strata to the north, along an estimated length of about 1220 m (4000 ft). The hydraulic conductivity ($K_j$) of the Jackpile sandstone in the area is not well defined. It has been indicated that the sandstone is about four times less transmissive in the area east of Rio Moquino than in the Paguate area west of Rio Moquino (Hydro-Search 1981). For conservatism, the hydraulic conductivity of 0.09 m/day (0.3 ft/day) that was used in the calculations for the South Paguate pit area also was used for the Jackpile pit area. The saturated thickness of the Jackpile sandstone ranges from 35 to 40 m (115 to 130 ft) at wells M14, M15, and M19, thus 37 m (120 ft) was used as an average. The equilibrium hydraulic gradient ($I_j$) in th Jackpile sandstone was not known and had to be estimated. The assumed value, as explained previously, would have to be tested against the calculated groundwater level. Discharge from local infiltration was considered at the Jackpile pit area in a way similar to what was done for the South Paguate pit. The drainage area for Jackpile pit is about $1.9 \times 10^6$ $m^2$ (475 ac).

Other parameters used in the calculation included the hydraulic conductivity values for backfill and alluvium--58 m/day (190 ft/day) and 7 m/day (22 ft/day), respectively. All groundwater from the Jackpile pit was assumed to flow along the path indicated in Figure C.12 through a stream length of about 760 m (2500 ft) along the Rio Paguate. The calculations were made for three downstream control depths ($h_o$)--0, 0.6, and 1.5 m (0, 2, and 5 ft)--to include the maximum possible water level in the Rio Paguate. As indicated in Figure C.14, groundwater discharge in the Jackpile pit area would flow across at least four boundaries. The water level at each boundary was calculated using the downstream water control level and the appropriate parameter values within each transport medium.

The equilibrium groundwater levels in the South Paguate and Jackpile pits were estimated by application of Eqs. C.4-1 and C.4-2 to the parameters discussed in the previous sections. The results are presented and discussed in Sections 5.5 and 5.6 in the main text of this report. The calculated differences between the water level in backfill at the southern end of the South Paguate pit and the stream bed level ($\Delta h$) are shown in Table 5.2; results for the Jackpile pit are shown in Table 5.4.

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## APPENDIX D. SELECTED RESULTS AND INPUT PARAMETERS USED IN RADIOLOGICAL ANALYSIS OF ATMOSPHERIC EXPOSURE PATHWAYS

## D.1 DETERMINATION OF RADON FLUX

Radon flux ($\Phi$), i.e., the rate of release of radon (Rn-222) from a unit area of soil surface per unit time (pCi Rn-222/$m^2 \cdot s$), is primarily dependent upon the concentration of radium (Ra-226) in the soil below the surface area. Specific flux ($\Phi_s$), i.e., radon flux per unit concentration of radium ([pCi Rn-222/ $m^2 \cdot s$]/ [pCi Ra-226/g]), is dependent, among other factors, upon the physical characteristics (such as compaction), type (such as sand vs clay), and moisture content of the soil.

Specific flux ($\phi_s$) is given by:

$$\phi_s = E \cdot \rho \cdot [Ra] \cdot \sqrt{\lambda D/P} \qquad \text{(D-1)}$$

where E = emanating power

$\rho$ = soil density

[Ra] = radium concentration

$\lambda$ = decay coefficient of radon

D = diffusion coefficient of radon through soil

P = soil porosity.

For this analysis, $\phi_s$ was calculated based on $E = 0.25$, $\rho = 1.6$ (g/$cm^3$), [Ra] = 1 pCi Ra-226/g, $\lambda = 2.1 \times 10^{-6}$ $s^{-1}$, $D = 2 \times 10^{-3}$ $cm^2$/s, and $P = 0.3$. These values are the midrange of the values reported in the literature (Kraner et al. 1964, Momeni et al. 1979, Momeni and Kretz 1980, Roger et al. 1980, USNRC 1980, and Wilkening et al. 1964). Based on these values, the specific flux ($\phi_s$) = 0.5 [pCi Rn-222/$m^2 \cdot s$]/[pCi Ra-226/g].

This specific flux was used to calculate flux and annual radon release rate. The annual release rate ($\dot{Q}$) from each area of the mine (A) was calculated from:

$$\dot{Q} = \Gamma \cdot A \, \Phi_s \, [Ra] \text{ Ci/yr} \qquad \text{(D.1-2)}$$

where $\Gamma = 3.154 \times 10^7$ s/yr .

Radon flux for various soils and conditions have been previously reported (Kraner et al. 1964, Momeni et al. 1979, Roger et al. 1980, Wilkening et al. 1964). The range of specific flux representative of the western uranium mining region of the United States is 0.4 to 0.7 [pCi Rn-222/$m^2 \cdot s$]/[pCi Ra-226/g] (USNRC 1980). The average specific flux for acid tailings at the Anaconda uranium mill is 0.65 and for carbonate tailings is 0.3 [pCi Rn-222/$m^2 \cdot s$]/ [pCi Ra-226/g] (Momeni et al. 1979). The value of flux from an aluvium soil as continuously measured on a location at the St. Anthony mine near Paguate, New Mexico, is within a range of 0.5 to 1.14 pCi Rn-222/$m^2 \cdot s$ (Momeni and Kretz

1980). The average concentration of radium measured in a composite core sample was 1.7 pCi Ra-226/g, resulting in a range of specific flux from 0.3 to 0.7 [pCi Rn-222/$m^2 \cdot s$]/[pCi Rn-226/g]. Thus, the specific-flux value of 0.5 [pCi Rn-222/ $m^2 \cdot s$]/[pCi Rn/g] selected for these calculations is within the range of those values previously reported.

The radon flux from the mine wastes that escapes through the surface of soil cover, $\phi_c$, is dependent on the same parameters given in Eq. D.1-1. Radon flux $\phi_c(z)$ through a soil cover of depth (z) is given by:

$$\phi_c\ (z) = \Phi\ (z = 0)\ f(z) \quad , \qquad (D.1\text{-}3)$$

where f(z) is the soil attenuation function. The values for f(z) have been previously measured (Momeni et al. 1979). The attenuation factor for soils typical of those around Grants, New Mexico, is given as a function of depth in Table D.1.

Table D.1. Radon Attenuation f(z) as a Function of Soil Depth (z)

| Depth (cm) | f(z) |
|---|---|
| 0 | 1.0 |
| 10 | 0.84 |
| 20 | 0.79 |
| 30 | 0.59 |
| 50 | 0.41 |
| 75 | 0.26 |
| 100 | 0.17 |
| 150 | 0.07 |
| 180 | 0.04 |
| 200 | 0.03 |

References for Appendix D.1

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Momeni, M.H., and N. Kretz. 1980. "Comparison of Radon Ground Flux with Air Concentration." pp. 43-48 in "Radon Release and Dispersion from an Open Pit Uranium Mine." NUREG/CR 1583, ANL/ES-97. Prepared by Argonne National Laboratory for U.S. Nuclear Regulatory Commission.

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Wilkening, M.H., W.E. Clements, and D. Stanley. 1964. "Radon-222 Flux Measurements in Widely Separated Regions." pp. 717-730 in "The Natural Radiation Environment." University of Chicago Press.

## D.2 INPUT PARAMETERS IN UDAD CODE

### D.2.1 Sources of Emissions

Table D.2. Selected Input Parameters for Pathway Analysis
(See Table D.3 for definitions of terms)

BSV(6):

| | | | | | |
|---|---|---|---|---|---|
| 2.50E-03 | 2.50E-03 | 4.20E-03 | 3.10E-04 | 6.80E-02 | 1.50E-01 |

DFACT = 5.00E-01

DM = 8.50E+02

DV(2):

| | |
|---|---|
| 7.50E-01 | 2.00E+00 |

FG = 1.00E+00

FOODIN(2,3):

| | |
|---|---|
| 5.00E+01 | 5.00E+01 |
| 6.00E+01 | 5.00E+01 |
| 3.00E-01 | 1.20E-01 |

FV(2):

| | |
|---|---|
| 2.00E-01 | 2.00E-01 |

F1(10):

| | | | | | |
|---|---|---|---|---|---|
| 1.00E-02 | 1.00E-02 | 1.00E-04 | 3.00E-01 | 8.00E-02 | 6.00E-02 |

F2P(10,4):

| | | | | | |
|---|---|---|---|---|---|
| 1.00E+00 | 1.00E+00 | 1.00E+00 | 5.40E-01 | 1.00E+00 | 1.00E+00 |
| 1.10E-01 | 1.10E-01 | 7.00E-01 | 5.40E-01 | 2.80E-01 | 1.00E-01 |
| 1.10E-01 | 1.10E-01 | 5.00E-02 | 2.00E-03 | 1.40E-01 | 7.00E-02 |
| 0.0 | 0.0 | 5.00E-02 | 4.00E-04 | 8.00E-02 | 1.70E-01 |

F2PM(16):

| | | | |
|---|---|---|---|
| 2.90E-01 | 1.10E-01 | 4.00E-02 | 2.00E-02 |
| 2.90E-01 | 1.10E-01 | 4.00E-02 | 2.00E-02 |

IDTAIL(5):

| | | | | |
|---|---|---|---|---|
| 1 | 2 | 3 | 0 | 0 |

IFOODS(60):

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 1 |
| 0 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 |
| 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 |

PACT(4,5):

| | | | |
|---|---|---|---|
| 2.06E+02 | 2.06E+02 | 2.06E+02 | 2.06E+02 |
| 1.95E+01 | 1.95E+01 | 1.95E+01 | 1.95E+01 |
| 4.37E+01 | 4.37E+01 | 4.37E+01 | 4.37E+01 |

PDEN(5):

| | | | | |
|---|---|---|---|---|
| 2.40E+00 | 2.40E+00 | 2.40E+00 | 2.40E+00 | 2.40E+00 |

Table D.2. Continued

PHALF = 1.00E+04

PTAIL(7,5):

| | | | | | | |
|---|---|---|---|---|---|---|
| 2.40E+00 | 3.00E-02 | 1.00E-01 | 1.00E+02 | 1.00E+00 | 3.00E+00 | 1.00E-01 |
| 2.40E+00 | 3.00E-02 | 1.00E-01 | 1.00E+02 | 1.00E+00 | 3.00E+00 | 1.00E-01 |
| 2.40E+00 | 3.00E-02 | 1.00E-01 | 1.00E+02 | 1.00E+00 | 3.00E+00 | 1.00E-01 |

PTSZ(5):

| | | | | |
|---|---|---|---|---|
| 2.00E-01 | 2.00E+00 | 1.00E+01 | 5.00E+01 | 1.00E+02 |

PTSZFC(5,5):

| | | | | |
|---|---|---|---|---|
| 1.50E-01 | 3.00E-01 | 3.00E-01 | 2.00E-01 | 5.00E-02 |
| 1.50E-01 | 3.00E-01 | 3.00E-01 | 2.00E-01 | 5.00E-02 |
| 1.50E-01 | 3.00E-01 | 3.00E-01 | 2.00E-01 | 5.00E-02 |

PTSZ20(5):

| | | | | |
|---|---|---|---|---|
| 4.00E-01 | 4.00E-01 | 4.00E-01 | 4.00E-01 | 4.00E-01 |

RFI = 5.83E-01

RFIE = 5.83E-01

RHO(2):

| | |
|---|---|
| 2.40E+02 | 2.40E+02 |

RSALF = 1.37E-01

RSLIM = 1.00E-02

SHIED = 5.00E-01

SLIM = 1.00E-02

SUFF = 1.00E-09

SUFI = 1.00E-05

TC(2):

| | |
|---|---|
| 3.00E+01 | 6.00E+01 |

TH(2):

| | |
|---|---|
| 1.40E+01 | 1.40E+01 |

VDEP(5):

| | | | | |
|---|---|---|---|---|
| 2.30E-06 | 1.30E-04 | 3.10E-03 | 7.60E-02 | 3.00E-01 |

YEVD = 1.00E+02

Table D.2. Continued

Particle Parameters and Fractional Distributions:

| Diameter, microns | Deposition Vel., m/sec | Settling Vel., m/sec | Fraction of the Sizes |
|---|---|---|---|
| 0.2 | 2.88E-06 | 2.88E-06 | 0.150 |
| 2.0 | 2.88E-04 | 2.88E-04 | 0.300 |
| 10.0 | 7.20E-03 | 7.20E-03 | 0.300 |
| 50.0 | 1.80E-01 | 1.80E-01 | 0.200 |
| 100.0 | 7.20E-01 | 7.20E-01 | 0.050 |

# Table D.3. Definitions of Terms

| *Symbolic Name* | *Description* |
|---|---|
| &INDATA | This is the 2nd data deck card if ISTEP=0, 1, or 4. |
| &NEWSET | This is the 2nd data deck card if ISTEP=3 |
| *BSV (6) (i) | Concentration factor for plant uptake of nuclide i from soil, pCi/kg (plant)/pCi/kg (soil). Default values: i=1 U238 2.5E-3, i=2 U234 2.5E-3, i=3 Th230 4.2E-3 i=4 Ra226 3.1E-4, i=5 Pb210 6.8E-2, i=6 Po210 1.5E-1 |
| *DFACT | Decontamination factor for human consumed vegetation. Default value = 0.5. |
| DM | Annual average mixing depth, m. Default = 850. |
| *DV (2) (i) | Pastures and vegetation yields, kg/m2. Defaults: i=1 pastures 0.75, i=2 vegetation 2.0. |
| *E(10,12) (i,j) | Effective energy absorbed per disintegration (MEV*REM/DIS*RAD), where i and j denote the radionuclide and organ, respectively. Default values are based on ICRP reports. |

| j | Organ or body part |
|---|---|
| 1 | Nasopharyngeal |
| 2 | Tracheobronchial |
| 3 | Pulmonary |
| 4 | Whole body |
| 5 | Bone |
| 6 | Kidney |
| 7 | Liver |
| 8 | Stomach |
| 9 | Small intestine |
| 10 | Upper large intestine |
| 11 | Lower Large intestine |
| 12 | Lymph nodes |

Default values:

| j\i | U238 | U234 | Th230 | Ra226 | Pb210 | Po210 |
|---|---|---|---|---|---|---|
| 1 | 4.3E+1 | 4.9E+1 | 4.8E+1 | 1.1E+2 | 6.1E-1 | 5.5E+1 |
| 2 | 4.3E+1 | 4.9E+1 | 4.8E+1 | 1.1E+2 | 4.8E-1 | 5.5E+1 |
| 3 | 4.3E+1 | 4.9E+1 | 4.8E+1 | 1.1E+2 | 8.3E+0 | 5.5E+1 |
| 4 | 4.3E+1 | 4.9E+1 | 4.8E+1 | 1.1E+2 | 5.2E+0 | 5.5E+1 |
| 5 | 2.2E+2 | 2.4E+2 | 2.4E+2 | 1.1E+2 | 2.9E+1 | 2.8E+2 |
| 6 | 4.3E+1 | 4.9E+1 | 4.8E+1 | 1.1E+2 | 1.0E+1 | 5.5E+1 |
| 7 | 4.3E+1 | 4.9E+1 | 4.8E+1 | 1.1E+2 | 1.0E+1 | 5.5E+1 |
| 8 | 4.3E-1 | 4.8E-1 | 4.7E-1 | 4.8E-1 | 2.7E-2 | 5.3E-1 |
| 9 | 4.3E-1 | 4.9E-1 | 4.7E-1 | 4.8E-1 | 4.5E-2 | 5.3E-1 |
| 10 | 4.3E-1 | 4.8E-1 | 4.7E-1 | 4.8E-1 | 1.9E-2 | 5.3E-1 |
| 11 | 4.3E-1 | 4.8E-1 | 4.7E-1 | 4.8E-1 | 1.9E-2 | 5.3E-1 |
| 12 | 4.3E+1 | 4.9E+1 | 4.8E+1 | 1.1E+2 | 2.5E+1 | 5.5E+1 |

| | |
|---|---|
| *FCON (6,5) (i,j) | Stable element transfer data, day/kg, where i and j denote the radionuclide and the food item respectively. j values: 1=beef, 2=milk, 3=poultry, 4=eggs, 5=vegetation Default values: |

| j\i | U238 | U234 | Th230 | Ra226 | Pb210 | Po210 |
|---|---|---|---|---|---|---|
| 1 | 3.4E-4 | 3.4E-4 | 2.0E-4 | 4.0E-3 | 2.9E-4 | 1.2E-2 |
| 2 | 6.1E-4 | 6.1E-4 | 5.0E-6 | 4.5E-4 | 2.6E-4 | 1.4E-4 |
| 3 | 4.0E-3 | 4.0E-3 | 4.0E-3 | 5.0E-4 | 2.0E-3 | 4.0E-3 |
| 4 | 2.0E-3 | 2.0E-3 | 2.0E-3 | 2.0E-5 | 2.0E-3 | 1.8E-2 |
| 5 | 2.0E+0 | 2.0E+0 | 3.0E+1 | 5.0E+1 | 1.0E+2 | 5.0E+2 |

Table D.3. Continued.

| *Symbolic Name* | *Description* |
|---|---|
| *F1 (10) (i) | Fraction of radionuclide i passing from GI tract to the blood. Default values are based on ICRP2. Defaults: i=1 U238 1.0E-2, i=2 U234 1.0E-2, i=3 Th230 1.0E-4, i=4 Ra226 3.0E-1, i=5 Pb210 8.0E-2, i=6 Po210 6.0E-2 |
| *F2P (10,4) (i,j) | Fraction of radionuclide i passing from blood to body organ j. j values: 1=whole body, 2=bone, 3=kidney, 4=liver. Defaults: |

| j\i | U238 | U234 | Th230 | Ra226 | Pb210 | Po210 |
|---|---|---|---|---|---|---|
| 1 | 1.0E+0 | 1.0E+0 | 1.0E+0 | 5.4E-1 | 1.0E+0 | 1.0E+0 |
| 2 | 1.1E-1 | 1.1E-1 | 7.0E-1 | 5.4E-1 | 2.8E-1 | 1.0E-1 |
| 3 | 1.1E-1 | 1.1E-1 | 5.0E-2 | 2.0E-3 | 1.4E-1 | 7.0E-2 |
| 4 | 0.0 | 0.0 | 5.0E-2 | 4.0E-4 | 8.0E-2 | 1.7E-1 |

| *Symbolic Name* | *Description* |
|---|---|
| *F2PM (16) | Multiple subpath values of F2P, see MSPTAB. Defaults: |

| | | | |
|---|---|---|---|
| 2.9E-1 | 1.1E-1 | 4.0E-2 | 2.0E-2 |
| 2.9E-1 | 1.1E-1 | 4.0E-2 | 2.0E-2 |
| 0.0 | 0.0 | 0.0 | 0.0 |
| 0.0 | 0.0 | 0.0 | 0.0 |

| *Symbolic Name* | *Description* |
|---|---|
| *FG | Grazing factor, default=0.5. |
| *FOODIN (2,3) (i,j) | Animal food ingestion rate, kg/day, where i and j denote the food category and animal type respectively. Defaults: |

| i\j | beef cattle | milk cows | poultry |
|---|---|---|---|
| water | 50 | 60 | 0.3 |
| pasture | 50 | 50 | 0.12 |

| *Symbolic Name* | *Description* |
|---|---|
| FREQ (16,6,6) (i,j,k) | Annual relative frequency of occurence for wind direction i, wind speed class j, and stablity class k. For each stability class and wind speed the frequencies are entered in a clockwise direction beginning with the north sector. No defaults; values must be input. |
| *FV (2) (i) | Fraction of deposition retained on plants. Default values: i=1 pasture 0.2, i=2 vegetation 0.2. |
| GROUPN(5,9) (i,j) | Any desired combination of 20 letters and numbers which will serve as an identifier on the printed output for the jth source type, i.e., mine, dryer, etc. (Card entry consists of groups of 4 characters, each enclosed in single quotation marks followed by a comma.) |
| IADD | Number of extra receptors, allowable range 0-60, default=0. |
| IDSQ (3,6) (i,j) | Identifies area sources to be broken up into equal size squares: i=1, SOURCE(10,k) or four digit identifier for kth source; i=2, number of squares in EW direction, i=3, number of squares in NS direction; all for jth source selected to be broken up. No defaults. |
| IDTAIL (5) (i) | Identification of up to 5 types of area source where the UDAD wind errosion equation will be used for particulate source estimation. Each ith value must be identical to the source type index of SORCE, i.e., the 2nd integer of SORCE(10,j) for the jth source. Area sources so selected may specify zero emission rate for all pollutants except Rn222. No defaults. |

Table D.3. Continued.

| *Symbolic Name* | *Description* |
|---|---|
| *IFODOS (60)<br>(i) | Food pathway index for the ith extra receptor. 0=none,<br>1=meat, 2=milk, 3=poultry & eggs, 5=vegetation. Default=0. |
| IPOP (15,16)<br>(i,j) | Population of sector-segment centered at ith radial.<br>distance and jth direction. |
| *IPSOL (10)<br>(i) | Solubility class (1=Y, 2=W, 3=D) for ith radionuclide.<br>Defaults: i=1 U238 1, i=2 U234 1, i=3 Th230 1,<br>i=4 Ra226 2, i=4 Pb210 2, i=6 Po210 2. |
| *IRHO (6) | Specifies the six XRHO indices to be used for dosimetry<br>tables. Default: 1, 3, 7, 8, 12, 15 corresponding to<br>0.1, 1, 5, 10, 50, 80 km. |
| *IYR (10) | Selects end year for intervals in time-integrated dose<br>and dose rate calculations. Default: 1, 3, 5, 7, 10,<br>15, 20, 30, 50, 70 years. |
| *JC (9)<br>(i) | Program control flags: 0 turns action off, 1 turns it on.<br>Defaults = 0.<br>i=1, writes disk file for concentration plots.<br>i=2, writes disk file for isopleth plots.<br>i=3, prints EFFECTIVE DISPERSION FACTOR tables.<br>i=4, prints CONCENTRATION/MPC tables.<br>i=5, prints dose commitment tables.<br>i=6, prints time-integrated dose & dose rate tables.<br>i=7, currently not in use.<br>i=8, prints INDIVIDUAL SOURCE CONCENTRATION tables.<br>i=9, currently not in use. |
| KRHO | Specifies number of radial distances to be used for<br>regular receptor grid. Range 0-15, default = 15.<br>If set to zero, only extra receptors will be used,<br>which is frequently a convenient option. |
| *LON (10,4)<br>REAL (i,j) | Effective half-life in days for radionuclide i and<br>organ j. j values: 1=whole body, 2= bone, 3=kidney,<br>4=liver. Default values based ICRP reports. Defaults: |

| j\i | U238 | U234 | Th230 | Ra226 | Pb210 | Po210 |
|---|---|---|---|---|---|---|
| 1 | 1.0E+2 | 1.0E+2 | 5.7E+4 | 4.0E-1 | 1.2E+3 | 2.5E+1 |
| 2 | 3.0E+2 | 3.0E+2 | 7.3E+4 | 4.0E-1 | 2.4E+3 | 2.0E+1 |
| 3 | 1.5E+1 | 1.5E+1 | 2.2E+4 | 1.0E+1 | 4.9E+2 | 4.6E+1 |
| 4 | 0.0 | 0.0 | 5.7E+4 | 1.0E+1 | 1.5E+3 | 3.2E+1 |

| *Symbolic Name* | *Description* |
|---|---|
| *LONM (16)<br>Real | Multiple subpath values of LON, see MSPTAB. Defaults:<br>4.95E+0 5.78E+1 6.93E+2 5.33E+3<br>4.95E+0 5.78E+1 6.93E+2 5.33E+3<br>0.0 0.0 0.0 0.0<br>0.0 0.0 0.0 0.0 |
| *LR (10)<br>Real (i) | Radiological half-lifes in days for radionuclides of<br>interest. Defaults:<br>i=1 U238 1.6E12, i=2 U234 9.1E7, i=3 Th230 2.9E7<br>i=4 Ra226 5.9E5, i=5 Pb210 7.1E3, i=6 Po210 1.4E2 |
| METSET (4)<br>Real*8 | Any desired combination of 32 letters and numbers which<br>will serve as an identifier on the printed output for<br>the source of the meteorological data set. (Card entry<br>starts with a single quotation mark and ends with a<br>single quotation mark followed by a comma.) |

Table D.3. Continued.

| *Symbolic Name* | *Description* |
|---|---|
| *MPC (7,5) Real(i,j) | Maximum permissible concentration (or any desired limit) for normalization on the isopleth concentraion map, pCi/m3, for radionuclide i and organ j. Default values based on ICRP2 values. j values: 1=whole body, 2=bone, 3=lung, 4=kidney, 5=liver. Defaults: |

| i\j | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| U238 | 6.0E+2 | 2.0E+2 | 5.0E+1 | 3.0E+1 | 0.0 |
| U234 | 6.0E+2 | 2.0E+2 | 4.0E+1 | 4.0E+2 | 0.0 |
| Th230 | 5.0E+0 | 8.0E-1 | 3.0E+0 | 2.0E+0 | 7.0E+0 |
| Ra226 | 2.0E+1 | 1.0E-1 | 0.0 | 0.0 | 0.0 |
| Pb210 | 4.0E+2 | 7.0E+1 | 8.0E+1 | 4.0E+1 | 1.0E+2 |
| Po210 | 2.0E+3 | 2.0E+3 | 7.0E+1 | 2.0E+2 | 6.0E+2 |
| Rn222 | 0.0 | 0.0 | 3.0E+3 | 0.0 | 0.0 |

| | |
|---|---|
| *MSPTAB (10,4) (i,j) | Multiple subpath table for radionuclides i and organs j where multiple sets of F2P and LON values are required. A zero value indicates no subpath, units value (1-9) gives number of additional subpaths, and value/10 is entry index in F2P and LON arrays. j values: 1=whole body, 2=bone, 3=kidney, 4=liver. Defaults: |

| j\i | U238 | U234 | Th230 | Ra226 | Pb210 | Po210 |
|---|---|---|---|---|---|---|
| 1 | 0 | 0 | 0 | 14 | 0 | 0 |
| 2 | 0 | 0 | 0 | 54 | 0 | 0 |
| 3 | 0 | 0 | 0 | 0 | 0 | 0 |
| 4 | 0 | 0 | 0 | 0 | 0 | 0 |

| | |
|---|---|
| *NNUC | Total number of radionuclides of interest. UDAD allowable range is 1-6, default is 6. |
| NSORCE | Total number of sources. Input value must be actual number described via SORCE parameter. If IDSQ feature is used, UDAD will adjust to a corrected NSORCE. The maximum number of sources, including IDSQ components, is 80. |
| OPTIME | Plant operation lifetime, years. Default=15. |
| PACT (4,5) (i,j) | Activity in pCi/g of radionuclide i of particle size<20 um diameter of area source j. The j index corresponds to IDTAIL(j). i values: 1=U238, 2=Th230, 3=Ra226, 4=Po210. |
| PDEN (5) | Densities of five specified particle source indices, g/cm3. Defaults: 8.9, 2.4, 2.4, 2.4, 2.4. |
| *PFIN (8) (i) | Fraction of ith food produced within the region of interest that is consumed by the local population in the region. i values: 1=meat, 2=milk, 3=poultry, 4=eggs, 5=vegetation, 6-8 not assigned. Defaults: all=1.0. |
| *PGTH (4) (i) | Population growth rate = population at year Y(i)/population at the reference year Yo when sources start to release.<br>i=1, Y(i) = Yo + 1<br>i=2, Y(i) = Yo + (OPTIME + 1)/2<br>i=3, Y(i) = Yo + OPTIME + 1<br>i=4, Y(i) = Yo + OPTIME + YEVD/2 + 1<br>Defaults: all=1.0. |
| PHALF | Radionuclide removal half life from soil in years. Default=50. |

Table D.3. Continued.

| *Symbolic Name* | *Description* |
|---|---|
| PTAIL (7,5) (i,j) | Propterty of soil or tailings for the jth type of area source where j index corresponds to IDTAIL(j). i values: i=1, density of suspended particulates, gm/cm3. i=2, median diameter of the grain, cm. i=3, a dimensionless coefficient for grains with median diameter above 100 um, A=0.1. i=4, height above surface where wind speed measured, cm. i=5, surface roughness height, or height above surface where wind speed is zero, cm. i=6, particle mass percentage of soil < 20 um in diameter. i=7, water content in percent by weight. Defaults: |

| j\i | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| 1 | 2.4 | 0.03 | 0.1 | 100.0 | 1.0 | 3.0 | 0.1 |
| 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| *Symbolic Name* | *Description* |
|---|---|
| PTSZ (5) | Activity particle sizes, diameter in microns. Defaults=0. |
| PTSZFC (5,5) (i,j) | Particle size activity fraction for ith size and jth source. The i and j indices correspond to PTSZ(i) and PDEN(j) respectively. Defaults=0. |
| PTSZ20 (5) (i) | Activity fraction of suspended particulates with particle size < 20 um for ith area source. The i index corresponds to IDTAIL(i). Defaults: all=0.4. |
| *PWFOD (60) (i) | Amount of kth food item produced at added receptor i/ total kth food item produced within the region of interest. Defaults: all=1.0. |
| REGION (6) | Any desired combination of 24 letters and numbers which will serve as in identifier of the overall problem on the printed output. (Card input format is the same as for METSET.) |
| RFI | Average occupancy factor for the population inside a structure for inhalation of Rn222 daughters. Default=1.0. |
| *RFIE | Average occupancy factor inside a structure for protection against external radiation. Default=0.583. |
| *RHO (2) (i) | Effective surface density of soil for growing pastures and and vegetation, kg/m2. Defaults: i=1 pastures 2.4E2, i=2 vegetation 2.4E2. |
| *RSALF | Resuspension factor decay half life in years, default=0.137. |
| *RSLIM | Deposition velocity corresponding to the input resuspension factors SUFI and SUFF. Default=0.01 m/sec. |
| *SHIED | External radiation shielding factor for inside of a structure. Default=0.5. |
| SLIM | Minimum settling velocity to account for plume tilting, m/sec. Default = 0.01. |
| SLIP (5) (i) | Slip correction factor, for ith particle size, defaults = 1.0. |

Table D.3. Concluded.

| *Symbolic Name* | *Description* |
|---|---|
| **SOURCE (12,80) (i,j)** | Specification parameters for the jth source. i values:<br>i=1, horizontal (EW) coordinate of source, km.<br>i=2, vertical (NS) coordinate of source, km.<br>i=3, effective release height of source, m.<br>i=4, release area of source, km2 (zero for a point source).<br>i=5, annual average U238 emission rate, Ci/year.<br>i=6, annual average Th230 emission rate, Ci/year.<br>i=7, annual average Ra226 emission rate, Ci/year.<br>i=8, annual average Pb210 emission rate, Ci/year.<br>i=9, annual average Rn222 emission rate, Ci/year.<br>i=10, four digit integer for source j identification where the 1st integer is the source group index, the 2nd integer is the source type index, the 3rd & 4th integers represent the nth number of source falling into this source category.<br>i=11, particle density index, corresponds to PDEN(k).<br>i=12, exit velocity of source, m/sec. |
| **SORCID (5,9) (i,j)** | Any desired combination of 20 letters or numbers which will serve as an identifer on the printed output for the jth source group where j equals the 1st digit of SORCE(10,k) for the kth source. (Card entry is the same format as for GROUPN.) |
| ***SUFF** | Final resuspension factor. Default=1.0E-9/m. |
| ***SUFI** | Initial resuspension factor. Default=1.0E-5/m. |
| ***TC (2) (i)** | Plant exposure time, days. Defaults:<br>i=1 pastures 30, i=2 vegetation 60. |
| ***TW (2) (i)** | Weathering removal half life, days. Defaults:<br>i=1 pastures 14, i=2 vegetation 14. |
| **VDEP (5) (i)** | Deposition velocity, m/sec, for particle size PTSZ(i).<br>Defaults: all=0.01. |
| ***XIN (7) (i)** | Maximum individual food consumption rate, kg/day. See XING for defaults. |
| ***XING (7) (i)** | Average individual food consumption rate, kg/day. Defaults: (see below) |
| **XNAME (4,60) REAL*8 (i,j)** | Any desired combination of 32 letters and numbers which which will serve as an identifer on the printed output for extra receptor j. (Card input format is the same as for GROUPN except use 8 character groups). |
| **XRECEP (3,60) (i,j)** | Coordinates and height of jth extra receptor.<br>i=1, horizontal (EW) coordinate, km.<br>i=2, vertical (NS) coordinate, km.<br>i=3, height in m. |
| **XRHO (15)** | Fifteen radial distances to be used for regular receptor grid. Defaults: 0.1, 0.5, 1, 2, 3, 4, 5, 10, 20, 30, 40, 50, 60, 70, 80 km. (Note that actual numer of XRHO values used is set by KRHO). |
| ***YDOC** | Number of years to be used for internal dose commitment conversion factors. Default=50. |
| ***YEVD** | Number of years to be used for environmental dose commitment calculations. Default=100. |

XING defaults:

| | XIN | XING |
|---|---|---|
| i=1, meat | 0.3 | 0.26 |
| i=2, milk | 0.85 | 0.33 |
| i=3, poultry | 0.2 | 0.1 |
| i=4, eggs | 0.08 | 0.08 |
| i=5, vegetation | 0.77 | 0.28 |

From Momeni, M.H., et al. 1979. "The Uranium Dispersion and Dosimetry (UDAD) Code." NUREG/CR-0553, ANL/ES-72. Argonne National Laboratory for U.S. Nuclear Regulatory Commission.

## D.2.2 Concentrations of Radionuclides in Air and on Ground

Table D.4. Total Concentration in Air (pCi/m$^3$)

| IDENTIFICATION | X(KM) | Y(KM) | Z(M) | U238 | TH230 | RA226 | PB210 | PO210 | RN222 | WL |
|---|---|---|---|---|---|---|---|---|---|---|
| ALBUQUERQUE | 60.0 | 0.0 | 0.0 | 7.23E-07 | 7.23E-07 | 7.23E-07 | 7.67E-06 | 1.03E-06 | 9.24E-02 | 9.09E-07 |
| BIBO | -2.0 | 3.0 | 0.0 | 2.97E-04 | 2.97E-04 | 2.97E-04 | 3.45E-04 | 2.99E-04 | 3.15E+01 | 1.97E-04 |
| BLUEWATER | -60.0 | 30.0 | 0.0 | 1.05E-06 | 1.05E-06 | 1.05E-06 | 8.84E-06 | 1.39E-06 | 9.42E-02 | 9.29E-07 |
| BELEN | 50.0 | -40.0 | 0.0 | 5.66E-06 | 5.66E-06 | 5.66E-06 | 3.57E-05 | 6.98E-06 | 3.72E-01 | 3.66E-06 |
| CASA BLANCA | -10.0 | -10.0 | 0.0 | 1.04E-04 | 1.04E-04 | 1.04E-04 | 1.73E-04 | 1.07E-04 | 4.25E+00 | 3.88E-05 |
| CUBERO | -16.0 | -10.0 | 0.0 | 4.67E-05 | 4.67E-05 | 4.67E-05 | 9.78E-05 | 4.90E-05 | 2.35E+00 | 2.18E-05 |
| GRANTS- MILLAN | -40.0 | 0.0 | 0.0 | 1.36E-06 | 1.36E-06 | 1.36E-06 | 9.94E-06 | 1.74E-06 | 1.75E-01 | 1.70E-06 |
| JACKPILE-HOUSING | 0.0 | -0.2 | 0.0 | 2.66E-03 | 2.66E-03 | 2.66E-03 | 2.67E-03 | 2.66E-03 | 1.10E+02 | 3.62E-04 |
| LAGUNA AND ENCINAL | -5.0 | 10.0 | 0.0 | 9.52E-05 | 9.52E-05 | 9.52E-05 | 2.44E-04 | 1.02E-04 | 1.37E+01 | 1.20E-04 |
| LOS LUNAS | 60.0 | -30.0 | 0.0 | 2.43E-06 | 2.43E-06 | 2.43E-06 | 1.73E-05 | 3.08E-06 | 1.87E-01 | 1.85E-06 |
| MESITA | 3.0 | -12.0 | 0.0 | 8.36E-04 | 8.36E-04 | 8.36E-04 | 1.05E-03 | 8.45E-04 | 1.74E+01 | 1.52E-04 |
| MONITOR AT DUMP F | 2.7 | 0.0 | 20.0 | 2.25E-03 | 2.25E-03 | 2.25E-03 | 2.27E-03 | 2.25E-03 | 8.06E+01 | 3.11E-04 |
| MONITOR AT WELL 4 | -0.7 | 2.3 | 1.0 | 5.79E-04 | 5.79E-04 | 5.79E-04 | 6.24E-04 | 5.81E-04 | 6.09E+01 | 3.18E-04 |
| MONITOR AT WEST SIDE | -2.0 | 0.7 | 1.0 | 1.52E-03 | 1.52E-03 | 1.52E-03 | 1.53E-03 | 1.52E-03 | 1.04E+02 | 2.04E-04 |
| MONITOR AT MINE VENT | -3.3 | -2.2 | 20.0 | 9.47E-04 | 9.47E-04 | 9.47E-04 | 9.99E-04 | 9.50E-04 | 2.90E+01 | 1.70E-04 |
| MOQUINO | -1.5 | 5.0 | 0.0 | 3.10E-04 | 3.10E-04 | 3.10E-04 | 4.41E-04 | 3.16E-04 | 4.18E+01 | 3.09E-04 |
| PAGUATE | 3.0 | 1.0 | 0.0 | 9.67E-04 | 9.67E-04 | 9.67E-04 | 9.88E-04 | 9.68E-04 | 4.49E+01 | 1.93E-04 |
| SEAMA | -14.0 | -10.0 | 0.0 | 6.17E-05 | 6.17E-05 | 6.17E-05 | 1.18E-04 | 6.42E-05 | 2.87E+00 | 2.65E-05 |
| SAN FIDEL | -25.0 | 0.0 | 0.0 | 3.19E-06 | 3.19E-06 | 3.19E-06 | 1.43E-05 | 3.67E-06 | 3.86E-01 | 3.64E-06 |
| SAN MATEO | -20.0 | 30.0 | 0.0 | 1.37E-05 | 1.37E-05 | 1.37E-05 | 1.01E-04 | 1.75E-05 | 1.91E+00 | 1.86E-05 |
| SABOYETA | 0.0 | 10.0 | 0.0 | 1.25E-04 | 1.25E-04 | 1.25E-04 | 2.28E-04 | 1.30E-04 | 1.30E+01 | 1.07E-04 |
| RANGE NORTH | 0.0 | 5.0 | 0.0 | 4.07E-04 | 4.07E-04 | 4.07E-04 | 5.27E-04 | 4.13E-04 | 5.08E+01 | 3.52E-04 |
| RANGE EAST | -15.0 | 0.0 | 0.0 | 8.40E-06 | 8.40E-06 | 8.40E-06 | 2.28E-05 | 9.03E-06 | 9.30E-01 | 8.26E-06 |
| RANGE WEST | -5.0 | 0.0 | 0.0 | 8.01E-05 | 8.01E-05 | 8.01E-05 | 1.00E-04 | 8.09E-05 | 6.83E+00 | 4.67E-05 |
| RANGE SOUTH | 0.0 | -10.0 | 0.0 | 5.58E-04 | 5.58E-04 | 5.58E-04 | 6.47E-04 | 5.62E-04 | 1.01E+01 | 8.41E-05 |

Table D.5. Total Activity on Ground (pCi/m$^2$)
[Operational lifetime deposition (99 years)]

| IDENTIFICATION | X(KM) | Y(KM) | Z(M) | U238 | TH230 | RA226 | PB210 | PO210 |
|---|---|---|---|---|---|---|---|---|
| ALBUQUERQUE | 60.00 | 0.0 | 0.0 | 5.07E+00 | 5.07E+00 | 5.07E+00 | 2.12E+01 | 2.11E+01 |
| BIBO | -2.00 | 3.00 | 0.0 | 1.01E+04 | 1.01E+04 | 1.01E+04 | 1.02E+04 | 1.02E+04 |
| BLUEWATER | -60.00 | 30.00 | 0.0 | 7.83E+00 | 7.83E+00 | 7.83E+00 | 2.59E+01 | 2.58E+01 |
| BELEN | 50.00 | -40.00 | 0.0 | 4.54E+01 | 4.54E+01 | 4.54E+01 | 1.15E+02 | 1.15E+02 |
| CASA BLANCA | -10.00 | -10.00 | 0.0 | 2.12E+03 | 2.12E+03 | 2.12E+03 | 2.28E+03 | 2.28E+03 |
| CUBERO | -16.00 | -10.00 | 0.0 | 7.67E+02 | 7.67E+02 | 7.67E+02 | 8.85E+02 | 8.85E+02 |
| GRANTS- MILLAN | -40.00 | 0.0 | 0.0 | 1.04E+01 | 1.04E+01 | 1.04E+01 | 3.02E+01 | 3.02E+01 |
| JACKPILE-HOUSING | 0.0 | -0.20 | 0.0 | 1.76E+05 | 1.76E+05 | 1.76E+05 | 1.76E+05 | 1.76E+05 |
| LAGUNA AND ENCINAL | -5.00 | 10.00 | 0.0 | 1.57E+03 | 1.57E+03 | 1.57E+03 | 1.92E+03 | 1.92E+03 |
| LOS LUNAS | 60.00 | -30.00 | 0.0 | 1.82E+01 | 1.82E+01 | 1.82E+01 | 5.26E+01 | 5.25E+01 |
| MESITA | 3.00 | -12.00 | 0.0 | 1.93E+04 | 1.93E+04 | 1.93E+04 | 1.98E+04 | 1.98E+04 |
| MONITOR AT DUMP F | 2.70 | 0.0 | 20.00 | 1.31E+05 | 1.31E+05 | 1.31E+05 | 1.31E+05 | 1.31E+05 |
| MONITOR AT WELL 4 | -0.70 | 2.30 | 1.00 | 2.31E+04 | 2.31E+04 | 2.31E+04 | 2.32E+04 | 2.32E+04 |
| MONITOR AT WEST SIDE | -2.00 | 0.70 | 1.00 | 1.29E+05 | 1.29E+05 | 1.29E+05 | 1.29E+05 | 1.29E+05 |
| MONITOR AT MINE VENT | -3.30 | -2.20 | 20.00 | 4.34E+04 | 4.34E+04 | 4.34E+04 | 4.35E+04 | 4.35E+04 |
| MOQUINO | -1.50 | 5.00 | 0.0 | 7.83E+03 | 7.83E+03 | 7.83E+03 | 8.13E+03 | 8.13E+03 |
| PAGUATE | 3.00 | 1.00 | 0.0 | 4.47E+04 | 4.47E+04 | 4.47E+04 | 4.48E+04 | 4.48E+04 |
| SEAMA | -14.00 | -10.00 | 0.0 | 1.09E+03 | 1.09E+03 | 1.09E+03 | 1.22E+03 | 1.22E+03 |
| SAN FIDEL | -25.00 | 0.0 | 0.0 | 2.94E+01 | 2.94E+01 | 2.94E+01 | 5.50E+01 | 5.50E+01 |
| SAN MATEO | -20.00 | 30.00 | 0.0 | 1.27E+02 | 1.27E+02 | 1.27E+02 | 3.30E+02 | 3.30E+02 |
| SABOYETA | 0.0 | 10.00 | 0.0 | 2.13E+03 | 2.13E+03 | 2.13E+03 | 2.37E+03 | 2.37E+03 |
| RANGE NORTH | 0.0 | 5.00 | 0.0 | 1.02E+04 | 1.02E+04 | 1.02E+04 | 1.04E+04 | 1.04E+04 |
| RANGE EAST | -15.00 | 0.0 | 0.0 | 1.05E+02 | 1.05E+02 | 1.05E+02 | 1.38E+02 | 1.38E+02 |
| RANGE WEST | -5.00 | 0.0 | 0.0 | 2.18E+03 | 2.18E+03 | 2.18E+03 | 2.23E+03 | 2.23E+03 |
| RANGE SOUTH | 0.0 | -10.00 | 0.0 | 1.48E+04 | 1.48E+04 | 1.48E+04 | 1.50E+04 | 1.50E+04 |

## D.3 DOSIMETRY

### D.3.1 Inhalation Dose Commitments

Table D.6. Inhalation Dose Commitments (mrem/yr) to Nasopharyngeal Region from Particulates

| IDENTIFICATION | X(KM) | Y(KM) | Z(M) | U238 | U234 | TH230 | RA226 | PB210 | PO210 | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|
| ALBUQUERQUE | 60.00 | 0.0 | 0.0 | 3.01E-03 | 3.43E-03 | 3.36E-03 | 7.01E-03 | 8.15E-05 | 3.66E-03 | 2.05E-02 |
| BIBO | -2.00 | 3.00 | 0.0 | 1.32E+00 | 1.50E+00 | 1.47E+00 | 3.07E+00 | 1.73E-02 | 1.53E+00 | 8.91E+00 |
| BLUEWATER | -60.00 | 30.00 | 0.0 | 4.39E-03 | 5.00E-03 | 4.90E-03 | 1.02E-02 | 1.05E-04 | 5.29E-03 | 2.99E-02 |
| BELEN | 50.00 | -40.00 | 0.0 | 2.38E-02 | 2.71E-02 | 2.65E-02 | 5.54E-02 | 4.92E-04 | 2.83E-02 | 1.62E-01 |
| CASA BLANCA | -10.00 | -10.00 | 0.0 | 4.54E-01 | 5.17E-01 | 5.07E-01 | 1.06E+00 | 6.29E-03 | 5.29E-01 | 3.07E+00 |
| CUBERO | -16.00 | -10.00 | 0.0 | 2.02E-01 | 2.30E-01 | 2.25E-01 | 4.70E-01 | 2.92E-03 | 2.36E-01 | 1.37E+00 |
| GRANTS- MILLAN | -40.00 | 0.0 | 0.0 | 5.71E-03 | 6.51E-03 | 6.37E-03 | 1.33E-02 | 1.27E-04 | 6.84E-03 | 3.89E-02 |
| JACKPILE-HOUSING | 0.0 | -0.20 | 0.0 | 1.22E+01 | 1.39E+01 | 1.36E+01 | 2.84E+01 | 1.57E-01 | 1.41E+01 | 8.23E+01 |
| LAGUNA AND ENCINAL | -5.00 | 10.00 | 0.0 | 4.11E-01 | 4.68E-01 | 4.59E-01 | 9.58E-01 | 6.23E-03 | 4.81E-01 | 2.78E+00 |
| LOS LUNAS | 60.00 | -30.00 | 0.0 | 1.01E-02 | 1.16E-02 | 1.13E-02 | 2.36E-02 | 2.22E-04 | 1.21E-02 | 6.90E-02 |
| MESITA | 3.00 | -12.00 | 0.0 | 3.65E+00 | 4.16E+00 | 4.08E+00 | 8.52E+00 | 4.85E-02 | 4.25E+00 | 2.47E+01 |
| MONITOR AT DUMP F | 2.70 | 0.0 | 20.00 | 1.02E+01 | 1.17E+01 | 1.14E+01 | 2.38E+01 | 1.32E-01 | 1.19E+01 | 6.92E+01 |
| MONITOR AT WELL 4 | -0.70 | 2.30 | 1.00 | 2.59E+00 | 2.95E+00 | 2.89E+00 | 6.03E+00 | 3.37E-02 | 3.01E+00 | 1.75E+01 |
| MONITOR AT WEST SIDE | -2.00 | 0.70 | 1.00 | 7.03E+00 | 8.01E+00 | 7.84E+00 | 1.64E+01 | 9.09E-02 | 8.17E+00 | 4.75E+01 |
| MONITOR AT MINE VENT | -3.30 | -2.20 | 20.00 | 4.26E+00 | 4.86E+00 | 4.76E+00 | 9.93E+00 | 5.54E-02 | 4.95E+00 | 2.88E+01 |
| MOQUINO | -1.50 | 5.00 | 0.0 | 1.36E+00 | 1.55E+00 | 1.52E+00 | 3.17E+00 | 1.84E-02 | 1.58E+00 | 9.20E+00 |
| PAGUATE | 3.00 | 1.00 | 0.0 | 4.35E+00 | 4.95E+00 | 4.85E+00 | 1.01E+01 | 5.63E-02 | 5.05E+00 | 2.94E+01 |
| SEAMA | -14.00 | -10.00 | 0.0 | 2.67E-01 | 3.04E-01 | 2.98E-01 | 6.23E-01 | 3.80E-03 | 3.12E-01 | 1.81E+00 |
| SAN FIDEL | -25.00 | 0.0 | 0.0 | 1.35E-02 | 1.54E-02 | 1.51E-02 | 3.15E-02 | 2.43E-04 | 1.60E-02 | 9.17E-02 |
| SAN MATEO | -20.00 | 30.00 | 0.0 | 5.79E-02 | 6.60E-02 | 6.46E-02 | 1.35E-01 | 1.29E-03 | 6.94E-02 | 3.94E-01 |
| SABOYETA | 0.0 | 10.00 | 0.0 | 5.42E-01 | 6.17E-01 | 6.05E-01 | 1.26E+00 | 7.64E-03 | 6.32E-01 | 3.67E+00 |
| RANGE NORTH | 0.0 | 5.00 | 0.0 | 1.78E+00 | 2.03E+00 | 1.99E+00 | 4.16E+00 | 2.38E-02 | 2.08E+00 | 1.21E+01 |
| RANGE EAST | -15.00 | 0.0 | 0.0 | 3.60E-02 | 4.10E-02 | 4.01E-02 | 8.39E-02 | 5.53E-04 | 4.22E-02 | 2.44E-01 |
| RANGE WEST | -5.00 | 0.0 | 0.0 | 3.52E-01 | 4.01E-01 | 3.93E-01 | 8.20E-01 | 4.67E-03 | 4.09E-01 | 2.38E+00 |
| RANGE SOUTH | 0.0 | -10.00 | 0.0 | 2.45E+00 | 2.79E+00 | 2.74E+00 | 5.71E+00 | 3.22E-02 | 2.85E+00 | 1.66E+01 |

Table D.7. Inhalation Dose Commitments (mrem/yr) to Tracheobronchial Region from Particulates

| IDENTIFICATION | X(KM) | Y(KM) | Z(M) | U238 | U234 | TH230 | RA226 | PB210 | PO210 | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|
| ALBUQUERQUE | 60.00 | 0.0 | 0.0 | 1.66E-06 | 1.89E-06 | 1.85E-06 | 3.48E-06 | 3.25E-07 | 2.93E-06 | 1.21E-05 |
| BIBO | -2.00 | 3.00 | 0.0 | 6.29E-04 | 7.16E-04 | 7.02E-04 | 1.29E-03 | 7.77E-06 | 5.92E-04 | 3.94E-03 |
| BLUEWATER | -60.00 | 30.00 | 0.0 | 2.41E-06 | 2.74E-06 | 2.69E-06 | 5.04E-06 | 3.69E-07 | 3.80E-06 | 1.70E-05 |
| BELEN | 50.00 | -40.00 | 0.0 | 1.29E-05 | 1.47E-05 | 1.44E-05 | 2.69E-05 | 1.46E-06 | 1.80E-05 | 8.83E-05 |
| CASA BLANCA | -10.00 | -10.00 | 0.0 | 2.27E-04 | 2.59E-04 | 2.53E-04 | 4.70E-04 | 5.09E-06 | 2.25E-04 | 1.44E-03 |
| CUBERO | -16.00 | -10.00 | 0.0 | 1.03E-04 | 1.17E-04 | 1.15E-04 | 2.13E-04 | 3.21E-06 | 1.06E-04 | 6.56E-04 |
| GRANTS- MILLAN | -40.00 | 0.0 | 0.0 | 3.10E-06 | 3.53E-06 | 3.46E-06 | 6.48E-06 | 4.11E-07 | 4.59E-06 | 2.16E-05 |
| JACKPILE-HOUSING | 0.0 | -0.20 | 0.0 | 5.35E-03 | 6.09E-03 | 5.97E-03 | 1.09E-02 | 4.81E-05 | 4.91E-03 | 3.33E-02 |
| LAGUNA AND ENCINAL | -5.00 | 10.00 | 0.0 | 2.09E-04 | 2.38E-04 | 2.33E-04 | 4.34E-04 | 8.52E-06 | 2.24E-04 | 1.35E-03 |
| LOS LUNAS | 60.00 | -30.00 | 0.0 | 5.56E-06 | 6.33E-06 | 6.20E-06 | 1.16E-05 | 7.13E-07 | 8.14E-06 | 3.86E-05 |
| MESITA | 3.00 | -12.00 | 0.0 | 1.81E-03 | 2.06E-03 | 2.02E-03 | 3.73E-03 | 2.58E-05 | 1.72E-03 | 1.14E-02 |
| MONITOR AT DUMP F | 2.70 | 0.0 | 20.00 | 4.58E-03 | 5.22E-03 | 5.11E-03 | 9.34E-03 | 4.17E-05 | 4.21E-03 | 2.85E-02 |
| MONITOR AT WELL 4 | -0.70 | 2.30 | 1.00 | 1.21E-03 | 1.38E-03 | 1.35E-03 | 2.49E-03 | 1.28E-05 | 1.13E-03 | 7.58E-03 |
| MONITOR AT WEST SIDE | -2.00 | 0.70 | 1.00 | 2.99E-03 | 3.40E-03 | 3.33E-03 | 6.05E-03 | 2.70E-05 | 2.73E-03 | 1.85E-02 |
| MONITOR AT MINE VENT | -3.30 | -2.20 | 20.00 | 1.96E-03 | 2.23E-03 | 2.19E-03 | 4.02E-03 | 1.98E-05 | 1.82E-03 | 1.22E-02 |
| MOQUINO | -1.50 | 5.00 | 0.0 | 6.68E-04 | 7.61E-04 | 7.46E-04 | 1.38E-03 | 1.18E-05 | 6.46E-04 | 4.21E-03 |
| PAGUATE | 3.00 | 1.00 | 0.0 | 2.00E-03 | 2.28E-03 | 2.23E-03 | 4.10E-03 | 1.88E-05 | 1.85E-03 | 1.25E-02 |
| SEAMA | -14.00 | -10.00 | 0.0 | 1.35E-04 | 1.54E-04 | 1.51E-04 | 2.80E-04 | 3.75E-06 | 1.37E-04 | 8.61E-04 |
| SAN FIDEL | -25.00 | 0.0 | 0.0 | 7.18E-06 | 8.18E-06 | 8.01E-06 | 1.50E-05 | 5.59E-07 | 8.89E-06 | 4.78E-05 |
| SAN MATEO | -20.00 | 30.00 | 0.0 | 3.08E-05 | 3.51E-05 | 3.44E-05 | 6.43E-05 | 4.19E-06 | 4.61E-05 | 2.15E-04 |
| SABOYETA | 0.0 | 10.00 | 0.0 | 2.75E-04 | 3.13E-04 | 3.07E-04 | 5.70E-04 | 7.07E-06 | 2.76E-04 | 1.75E-03 |
| RANGE NORTH | 0.0 | 5.00 | 0.0 | 8.77E-04 | 1.00E-03 | 9.79E-04 | 1.81E-03 | 1.32E-05 | 8.38E-04 | 5.52E-03 |
| RANGE EAST | -15.00 | 0.0 | 0.0 | 1.87E-05 | 2.13E-05 | 2.08E-05 | 3.88E-05 | 8.10E-07 | 2.03E-05 | 1.21E-04 |
| RANGE WEST | -5.00 | 0.0 | 0.0 | 1.72E-04 | 1.96E-04 | 1.92E-04 | 3.54E-04 | 2.44E-06 | 1.63E-04 | 1.08E-03 |
| RANGE SOUTH | 0.0 | -10.00 | 0.0 | 1.20E-03 | 1.36E-03 | 1.34E-03 | 2.47E-03 | 1.47E-05 | 1.13E-03 | 7.51E-03 |

Table D.8. Inhalation Dose Commitments (mrem/yr)
to Pulmonary Region from Particulates

| IDENTIFICATION | X(KM) | Y(KM) | Z(M) | U238 | U234 | TH230 | RA226 | PB210 | PO210 | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|
| ALBUQUERQUE | 60.00 | 0.0 | 0.0 | 1.28E-03 | 1.45E-03 | 1.42E-03 | 3.30E-04 | 6.16E-04 | 2.50E-04 | 5.35E-03 |
| BIBO | -2.00 | 3.00 | 0.0 | 4.60E-01 | 5.24E-01 | 5.13E-01 | 1.19E-01 | 1.30E-02 | 4.48E-02 | 1.67E+00 |
| BLUEWATER | -60.00 | 30.00 | 0.0 | 1.85E-03 | 2.10E-03 | 2.06E-03 | 4.78E-04 | 6.99E-04 | 3.20E-04 | 7.51E-03 |
| BELEN | 50.00 | -40.00 | 0.0 | 9.83E-03 | 1.12E-02 | 1.10E-02 | 2.55E-03 | 2.75E-03 | 1.49E-03 | 3.88E-02 |
| CASA BLANCA | -10.00 | -10.00 | 0.0 | 1.69E-01 | 1.92E-01 | 1.88E-01 | 4.37E-02 | 9.06E-03 | 1.74E-02 | 6.20E-01 |
| CUBERO | -16.00 | -10.00 | 0.0 | 7.68E-02 | 8.76E-02 | 8.58E-02 | 1.99E-02 | 5.83E-03 | 8.28E-03 | 2.84E-01 |
| GRANTS- MILLAN | -40.00 | 0.0 | 0.0 | 2.37E-03 | 2.70E-03 | 2.64E-03 | 6.13E-04 | 7.76E-04 | 3.84E-04 | 9.48E-03 |
| JACKPILE-HOUSING | 0.0 | -0.20 | 0.0 | 3.78E+00 | 4.31E+00 | 4.22E+00 | 9.79E-01 | 7.45E-02 | 3.61E-01 | 1.37E+01 |
| LAGUNA AND ENCINAL | -5.00 | 10.00 | 0.0 | 1.57E-01 | 1.78E-01 | 1.75E-01 | 4.05E-02 | 1.57E-02 | 1.77E-02 | 5.83E-01 |
| LOS LUNAS | 60.00 | -30.00 | 0.0 | 4.26E-03 | 4.85E-03 | 4.75E-03 | 1.10E-03 | 1.35E-03 | 6.80E-04 | 1.70E-02 |
| MESITA | 3.00 | -12.00 | 0.0 | 1.34E+00 | 1.53E+00 | 1.49E+00 | 3.46E-01 | 4.41E-02 | 1.32E-01 | 4.88E+00 |
| MONITOR AT DUMP F | 2.70 | 0.0 | 20.00 | 3.26E+00 | 3.72E+00 | 3.64E+00 | 8.44E-01 | 6.50E-02 | 3.12E-01 | 1.18E+01 |
| MONITOR AT WELL 4 | -0.70 | 2.30 | 1.00 | 8.81E-01 | 1.00E+00 | 9.83E-01 | 2.28E-01 | 2.08E-02 | 8.49E-02 | 3.20E+00 |
| MONITOR AT WEST SIDE | -2.00 | 0.70 | 1.00 | 2.08E+00 | 2.37E+00 | 2.32E+00 | 5.38E-01 | 4.15E-02 | 1.99E-01 | 7.55E+00 |
| MONITOR AT MINE VENT | -3.30 | -2.20 | 20.00 | 1.41E+00 | 1.61E+00 | 1.58E+00 | 3.66E-01 | 3.17E-02 | 1.36E-01 | 5.14E+00 |
| MOQUINO | -1.50 | 5.00 | 0.0 | 4.94E-01 | 5.63E-01 | 5.51E-01 | 1.28E-01 | 2.07E-02 | 4.96E-02 | 1.81E+00 |
| PAGUATE | 3.00 | 1.00 | 0.0 | 1.44E+00 | 1.65E+00 | 1.61E+00 | 3.74E-01 | 2.97E-02 | 1.38E-01 | 5.24E+00 |
| SEAMA | -14.00 | -10.00 | 0.0 | 1.01E-01 | 1.15E-01 | 1.13E-01 | 2.61E-02 | 6.77E-03 | 1.07E-02 | 3.72E-01 |
| SAN FIDEL | -25.00 | 0.0 | 0.0 | 5.45E-03 | 6.21E-03 | 6.08E-03 | 1.41E-03 | 1.05E-03 | 7.24E-04 | 2.09E-02 |
| SAN MATEO | -20.00 | 30.00 | 0.0 | 2.34E-02 | 2.67E-02 | 2.62E-02 | 6.07E-03 | 7.91E-03 | 3.85E-03 | 9.41E-02 |
| SABOYETA | 0.0 | 10.00 | 0.0 | 2.06E-01 | 2.34E-01 | 2.29E-01 | 5.32E-02 | 1.27E-02 | 2.15E-02 | 7.57E-01 |
| RANGE NORTH | 0.0 | 5.00 | 0.0 | 6.49E-01 | 7.39E-01 | 7.24E-01 | 1.68E-01 | 2.27E-02 | 6.42E-02 | 2.37E+00 |
| RANGE EAST | -15.00 | 0.0 | 0.0 | 1.41E-02 | 1.60E-02 | 1.57E-02 | 3.64E-03 | 1.49E-03 | 1.61E-03 | 5.25E-02 |
| RANGE WEST | -5.00 | 0.0 | 0.0 | 1.27E-01 | 1.44E-01 | 1.41E-01 | 3.28E-02 | 4.15E-03 | 1.25E-02 | 4.62E-01 |
| RANGE SOUTH | 0.0 | -10.00 | 0.0 | 8.83E-01 | 1.01E+00 | 9.86E-01 | 2.29E-01 | 2.47E-02 | 8.60E-02 | 3.22E+00 |

## Table D.9. Inhalation Dose Commitments (mrem/yr) to Whole Body from Particulates

| IDENTIFICATION | X(KM) | Y(KM) | Z(M) | U238 | U234 | TH230 | RA226 | PB210 | PO210 | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|
| ALBUQUERQUE | 60.00 | 0.0 | 0.0 | 1.04E-06 | 1.19E-06 | 1.37E-04 | 2.98E-05 | 5.85E-05 | 1.66E-06 | 2.29E-04 |
| BIBO | -2.00 | 3.00 | 0.0 | 4.01E-04 | 4.56E-04 | 5.15E-02 | 1.25E-02 | 3.11E-03 | 5.33E-04 | 6.85E-02 |
| BLUEWATER | -60.00 | 30.00 | 0.0 | 1.51E-06 | 1.72E-06 | 1.99E-04 | 4.34E-05 | 6.77E-05 | 2.28E-06 | 3.15E-04 |
| BELEN | 50.00 | -40.00 | 0.0 | 8.09E-06 | 9.22E-06 | 1.06E-03 | 2.34E-04 | 2.76E-04 | 1.16E-05 | 1.60E-03 |
| CASA BLANCA | -10.00 | -10.00 | 0.0 | 1.44E-04 | 1.64E-04 | 1.86E-02 | 4.37E-03 | 1.47E-03 | 1.89E-04 | 2.50E-02 |
| CUBERO | -16.00 | -10.00 | 0.0 | 6.50E-05 | 7.40E-05 | 8.44E-03 | 1.95E-03 | 8.12E-04 | 8.57E-05 | 1.14E-02 |
| GRANTS- MILLAN | -40.00 | 0.0 | 0.0 | 1.95E-06 | 2.22E-06 | 2.55E-04 | 5.63E-05 | 7.65E-05 | 2.88E-06 | 3.95E-04 |
| JACKPILE-HOUSING | 0.0 | -0.20 | 0.0 | 3.44E-03 | 3.92E-03 | 4.36E-01 | 1.13E-01 | 2.48E-02 | 4.78E-03 | 5.86E-01 |
| LAGUNA AND ENCINAL | -5.00 | 10.00 | 0.0 | 1.32E-04 | 1.51E-04 | 1.72E-02 | 3.97E-03 | 1.99E-03 | 1.77E-04 | 2.36E-02 |
| LOS LUNAS | 60.00 | -30.00 | 0.0 | 3.49E-06 | 3.97E-06 | 4.58E-04 | 1.00E-04 | 1.33E-04 | 5.10E-06 | 7.04E-04 |
| MESITA | 3.00 | -12.00 | 0.0 | 1.15E-03 | 1.31E-03 | 1.48E-01 | 3.50E-02 | 9.32E-03 | 1.50E-03 | 1.97E-01 |
| MONITOR AT DUMP F | 2.70 | 0.0 | 20.00 | 2.94E-03 | 3.35E-03 | 3.74E-01 | 9.53E-02 | 2.11E-02 | 4.04E-03 | 5.00E-01 |
| MONITOR AT WELL 4 | -0.70 | 2.30 | 1.00 | 7.74E-04 | 8.82E-04 | 9.92E-02 | 2.44E-02 | 5.70E-03 | 1.04E-03 | 1.32E-01 |
| MONITOR AT WEST SIDE | -2.00 | 0.70 | 1.00 | 1.93E-03 | 2.20E-03 | 2.43E-01 | 6.46E-02 | 1.42E-02 | 2.73E-03 | 3.29E-01 |
| MONITOR AT MINE VENT | -3.30 | -2.20 | 20.00 | 1.25E-03 | 1.43E-03 | 1.60E-01 | 4.00E-02 | 9.17E-03 | 1.70E-03 | 2.14E-01 |
| MOQUINO | -1.50 | 5.00 | 0.0 | 4.24E-04 | 4.84E-04 | 5.48E-02 | 1.30E-02 | 3.84E-03 | 5.59E-04 | 7.32E-02 |
| PAGUATE | 3.00 | 1.00 | 0.0 | 1.28E-03 | 1.46E-03 | 1.64E-01 | 4.08E-02 | 9.12E-03 | 1.73E-03 | 2.18E-01 |
| SEAMA | -14.00 | -10.00 | 0.0 | 8.56E-05 | 9.75E-05 | 1.11E-02 | 2.58E-03 | 9.92E-04 | 1.13E-04 | 1.50E-02 |
| SAN FIDEL | -25.00 | 0.0 | 0.0 | 4.52E-06 | 5.15E-06 | 5.91E-04 | 1.32E-04 | 1.12E-04 | 6.24E-06 | 8.51E-04 |
| SAN MATEO | -20.00 | 30.00 | 0.0 | 1.94E-05 | 2.21E-05 | 2.54E-03 | 5.68E-04 | 7.80E-04 | 2.90E-05 | 3.96E-03 |
| SABOYETA | 0.0 | 10.00 | 0.0 | 1.74E-04 | 1.98E-04 | 2.26E-02 | 5.24E-03 | 1.92E-03 | 2.28E-04 | 3.03E-02 |
| RANGE NORTH | 0.0 | 5.00 | 0.0 | 5.57E-04 | 6.35E-04 | 7.20E-02 | 1.71E-02 | 4.66E-03 | 7.31E-04 | 9.56E-02 |
| RANGE EAST | -15.00 | 0.0 | 0.0 | 1.18E-05 | 1.34E-05 | 1.54E-03 | 3.50E-04 | 1.85E-04 | 1.57E-05 | 2.11E-03 |
| RANGE WEST | -5.00 | 0.0 | 0.0 | 1.09E-04 | 1.24E-04 | 1.41E-02 | 3.36E-03 | 8.89E-04 | 1.44E-04 | 1.87E-02 |
| RANGE SOUTH | 0.0 | -10.00 | 0.0 | 7.61E-04 | 8.67E-04 | 9.82E-02 | 2.34E-02 | 5.82E-03 | 9.98E-04 | 1.30E-01 |

Table D.10. Inhalation Dose Commitments (mrem/yr) to Bone from Particulates

| IDENTIFICATION | X(KM) | Y(KM) | Z(M) | U238 | U234 | TH230 | RA226 | PB210 | PO210 | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|
| ALBUQUERQUE | 60.00 | 0.0 | 0.0 | 1.76E-05 | 1.92E-05 | 4.94E-03 | 2.98E-04 | 1.82E-03 | 6.76E-06 | 7.10E-03 |
| BIBO | -2.00 | 3.00 | 0.0 | 6.76E-03 | 7.38E-03 | 1.86E+00 | 1.25E-01 | 9.69E-02 | 2.17E-03 | 2.10E+00 |
| BLUEWATER | -60.00 | 30.00 | 0.0 | 2.55E-05 | 2.78E-05 | 7.17E-03 | 4.34E-04 | 2.11E-03 | 9.31E-06 | 9.77E-03 |
| BELEN | 50.00 | -40.00 | 0.0 | 1.37E-04 | 1.49E-04 | 3.83E-02 | 2.34E-03 | 8.58E-03 | 4.74E-05 | 4.95E-02 |
| CASA BLANCA | -10.00 | -10.00 | 0.0 | 2.43E-03 | 2.65E-03 | 6.73E-01 | 4.37E-02 | 4.59E-02 | 7.70E-04 | 7.68E-01 |
| CUBERO | -16.00 | -10.00 | 0.0 | 1.10E-03 | 1.20E-03 | 3.05E-01 | 1.95E-02 | 2.53E-02 | 3.49E-04 | 3.52E-01 |
| GRANTS- MILLAN | -40.00 | 0.0 | 0.0 | 3.29E-05 | 3.59E-05 | 9.22E-03 | 5.63E-04 | 2.38E-03 | 1.17E-05 | 1.22E-02 |
| JACKPILE-HOUSING | 0.0 | -0.20 | 0.0 | 5.80E-02 | 6.33E-02 | 1.57E+01 | 1.13E+00 | 7.75E-01 | 1.95E-02 | 1.78E+01 |
| LAGUNA AND ENCINAL | -5.00 | 10.00 | 0.0 | 2.23E-03 | 2.44E-03 | 6.20E-01 | 3.97E-02 | 6.18E-02 | 7.21E-04 | 7.27E-01 |
| LOS LUNAS | 60.00 | -30.00 | 0.0 | 5.89E-05 | 6.42E-05 | 1.65E-02 | 1.00E-03 | 4.13E-03 | 2.08E-05 | 2.18E-02 |
| MESITA | 3.00 | -12.00 | 0.0 | 1.94E-02 | 2.11E-02 | 5.35E+00 | 3.50E-01 | 2.91E-01 | 6.10E-03 | 6.04E+00 |
| MONITOR AT DUMP F | 2.70 | 0.0 | 20.00 | 4.96E-02 | 5.41E-02 | 1.35E+01 | 9.53E-01 | 6.57E-01 | 1.64E-02 | 1.52E+01 |
| MONITOR AT WELL 4 | -0.70 | 2.30 | 1.00 | 1.31E-02 | 1.43E-02 | 3.58E+00 | 2.44E-01 | 1.78E-01 | 4.22E-03 | 4.04E+00 |
| MONITOR AT WEST SIDE | -2.00 | 0.70 | 1.00 | 3.25E-02 | 3.55E-02 | 8.77E+00 | 6.46E-01 | 4.44E-01 | 1.11E-02 | 9.94E+00 |
| MONITOR AT MINE VENT | -3.30 | -2.20 | 20.00 | 2.12E-02 | 2.31E-02 | 5.79E+00 | 4.00E-01 | 2.86E-01 | 6.92E-03 | 6.53E+00 |
| MOQUINO | -1.50 | 5.00 | 0.0 | 7.17E-03 | 7.82E-03 | 1.98E+00 | 1.30E-01 | 1.20E-01 | 2.28E-03 | 2.25E+00 |
| PAGUATE | 3.00 | 1.00 | 0.0 | 2.16E-02 | 2.36E-02 | 5.91E+00 | 4.08E-01 | 2.85E-01 | 7.05E-03 | 6.66E+00 |
| SEAMA | -14.00 | -10.00 | 0.0 | 1.44E-03 | 1.58E-03 | 4.01E-01 | 2.58E-02 | 3.09E-02 | 4.59E-04 | 4.61E-01 |
| SAN FIDEL | -25.00 | 0.0 | 0.0 | 7.63E-05 | 8.33E-05 | 2.13E-02 | 1.32E-03 | 3.48E-03 | 2.54E-05 | 2.63E-02 |
| SAN MATEO | -20.00 | 30.00 | 0.0 | 3.28E-04 | 3.58E-04 | 9.17E-02 | 5.68E-03 | 2.42E-02 | 1.18E-04 | 1.22E-01 |
| SABOYETA | 0.0 | 10.00 | 0.0 | 2.94E-03 | 3.20E-03 | 8.16E-01 | 5.24E-02 | 5.99E-02 | 9.28E-04 | 9.35E-01 |
| RANGE NORTH | 0.0 | 5.00 | 0.0 | 9.41E-03 | 1.03E-02 | 2.60E+00 | 1.71E-01 | 1.45E-01 | 2.98E-03 | 2.94E+00 |
| RANGE EAST | -15.00 | 0.0 | 0.0 | 1.99E-04 | 2.17E-04 | 5.54E-02 | 3.50E-03 | 5.75E-03 | 6.38E-05 | 6.52E-02 |
| RANGE WEST | -5.00 | 0.0 | 0.0 | 1.84E-03 | 2.01E-03 | 5.08E-01 | 3.36E-02 | 2.77E-02 | 5.85E-04 | 5.74E-01 |
| RANGE SOUTH | 0.0 | -10.00 | 0.0 | 1.28E-02 | 1.40E-02 | 3.55E+00 | 2.34E-01 | 1.82E-01 | 4.06E-03 | 3.99E+00 |



 

Table D.11. Inhalation Dose Commitments (mrem/yr) to Bronchial Epithelium and Working Level Month (WLM) from Radon

| IDENTIFICATION | X(KM) | Y(KM) | Z(M) | DOSE RATE | WLM |
|---|---|---|---|---|---|
| ALBUQUERQUE | 60.00 | 0.0 | 0.0 | 5.78E-02 | 1.62E-05 |
| BIBO | -2.00 | 3.00 | 0.0 | 1.97E+01 | 4.35E-03 |
| BLUEWATER | -60.00 | 30.00 | 0.0 | 5.89E-02 | 1.65E-05 |
| BELEN | 50.00 | -40.00 | 0.0 | 2.33E-01 | 6.53E-05 |
| CASA BLANCA | -10.00 | -10.00 | 0.0 | 2.66E+00 | 7.14E-04 |
| CUBERO | -16.00 | -10.00 | 0.0 | 1.47E+00 | 3.98E-04 |
| GRANTS- MILLAN | -40.00 | 0.0 | 0.0 | 1.09E-01 | 3.04E-05 |
| JACKPILE-HOUSING | 0.0 | -0.20 | 0.0 | 6.87E+01 | 1.18E-02 |
| LAGUNA AND ENCINAL | -5.00 | 10.00 | 0.0 | 8.58E+00 | 2.26E-03 |
| LOS LUNAS | 60.00 | -30.00 | 0.0 | 1.17E-01 | 3.29E-05 |
| MESITA | 3.00 | -12.00 | 0.0 | 1.09E+01 | 2.85E-03 |
| MONITOR AT DUMP F | 2.70 | 0.0 | 20.00 | 5.04E+01 | 9.11E-03 |
| MONITOR AT WELL 4 | -0.70 | 2.30 | 1.00 | 3.81E+01 | 7.76E-03 |
| MONITOR AT WEST SIDE | -2.00 | 0.70 | 1.00 | 6.49E+01 | 9.69E-03 |
| MONITOR AT MINE VENT | -3.30 | -2.20 | 20.00 | 1.81E+01 | 3.89E-03 |
| MOQUINO | -1.50 | 5.00 | 0.0 | 2.61E+01 | 6.26E-03 |
| PAGUATE | 3.00 | 1.00 | 0.0 | 2.80E+01 | 5.28E-03 |
| SEAMA | -14.00 | -10.00 | 0.0 | 1.79E+00 | 4.85E-04 |
| SAN FIDEL | -25.00 | 0.0 | 0.0 | 2.41E-01 | 6.61E-05 |
| SAN MATEO | -20.00 | 30.00 | 0.0 | 1.19E+00 | 3.33E-04 |
| SABOYETA | 0.0 | 10.00 | 0.0 | 8.10E+00 | 2.06E-03 |
| RANGE NORTH | 0.0 | 5.00 | 0.0 | 3.18E+01 | 7.38E-03 |
| RANGE EAST | -15.00 | 0.0 | 0.0 | 5.82E-01 | 1.54E-04 |
| RANGE WEST | -5.00 | 0.0 | 0.0 | 4.27E+00 | 9.85E-04 |
| RANGE SOUTH | 0.0 | -10.00 | 0.0 | 6.30E+00 | 1.61E-03 |

## D.3.2 External Exposure Dose Commitments

### D.3.2.1 Ground Deposition



### D.3.2.2 Air

Table D.12. External Dose Commitments (mrem/yr) to Skin from Ground Deposition

| IDENTIFICATION | X(KM) | Y(KM) | Z(M) | U238 | U234 | TH230 | RA226 | PB210 | TOTAL |
|---|---|---|---|---|---|---|---|---|---|
| ALBUQUERQUE | 60.00 | 0.0 | 0.0 | 5.40E-03 | 9.34E-06 | 7.90E-06 | 4.83E-03 | 7.63E-03 | 1.79E-02 |
| BIBO | -2.00 | 3.00 | 0.0 | 1.07E+01 | 1.86E-02 | 1.57E-02 | 9.59E+00 | 3.67E+00 | 2.40E+01 |
| BLUEWATER | -60.00 | 30.00 | 0.0 | 8.34E-03 | 1.44E-05 | 1.22E-05 | 7.45E-03 | 9.32E-03 | 2.51E-02 |
| BELEN | 50.00 | -40.00 | 0.0 | 4.84E-02 | 8.37E-05 | 7.08E-05 | 4.32E-02 | 4.14E-02 | 1.33E-01 |
| CASA BLANCA | -10.00 | -10.00 | 0.0 | 2.26E+00 | 3.91E-03 | 3.31E-03 | 2.02E+00 | 8.23E-01 | 5.12E+00 |
| CUBERO | -16.00 | -10.00 | 0.0 | 8.17E-01 | 1.41E-03 | 1.20E-03 | 7.30E-01 | 3.19E-01 | 1.87E+00 |
| GRANTS- MILLAN | -40.00 | 0.0 | 0.0 | 1.11E-02 | 1.91E-05 | 1.62E-05 | 9.87E-03 | 1.09E-02 | 3.19E-02 |
| JACKPILE-HOUSING | 0.0 | -0.20 | 0.0 | 1.83E+02 | 3.25E-01 | 2.75E-01 | 1.68E+02 | 6.36E+01 | 4.20E+02 |
| LAGUNA AND ENCINAL | -5.00 | 10.00 | 0.0 | 1.68E+00 | 2.90E-03 | 2.45E-03 | 1.50E+00 | 6.90E-01 | 3.87E+00 |
| LOS LUNAS | 60.00 | -30.00 | 0.0 | 1.94E-02 | 3.36E-05 | 2.84E-05 | 1.73E-02 | 1.89E-02 | 5.58E-02 |
| MESITA | 3.00 | -12.00 | 0.0 | 2.06E+01 | 3.55E-02 | 3.01E-02 | 1.84E+01 | 7.13E+00 | 4.61E+01 |
| MONITOR AT DUMP F | 2.70 | 0.0 | 20.00 | 1.40E+02 | 2.42E-01 | 2.04E-01 | 1.25E+02 | 4.73E+01 | 3.12E+02 |
| MONITOR AT WELL 4 | -0.70 | 2.30 | 1.00 | 2.46E+01 | 4.25E-02 | 3.60E-02 | 2.20E+01 | 8.36E+00 | 5.50E+01 |
| MONITOR AT WEST SIDE | -2.00 | 0.70 | 1.00 | 1.37E+02 | 2.37E-01 | 2.01E-01 | 1.23E+02 | 4.64E+01 | 3.07E+02 |
| MONITOR AT MINE VENT | -3.30 | -2.20 | 20.00 | 4.63E+01 | 8.00E-02 | 6.77E-02 | 4.13E+01 | 1.57E+01 | 1.03E+02 |
| MOQUINO | -1.50 | 5.00 | 0.0 | 8.34E+00 | 1.44E-02 | 1.22E-02 | 7.45E+00 | 2.93E+00 | 1.87E+01 |
| PAGUATE | 3.00 | 1.00 | 0.0 | 4.77E+01 | 8.24E-02 | 6.97E-02 | 4.26E+01 | 1.61E+01 | 1.07E+02 |
| SEAMA | -14.00 | -10.00 | 0.0 | 1.16E+00 | 2.00E-03 | 1.70E-03 | 1.04E+00 | 4.39E-01 | 2.64E+00 |
| SAN FIDEL | -25.00 | 0.0 | 0.0 | 3.13E-02 | 5.41E-05 | 4.58E-05 | 2.80E-02 | 1.98E-02 | 7.92E-02 |
| SAN MATEO | -20.00 | 30.00 | 0.0 | 1.35E-01 | 2.34E-04 | 1.98E-04 | 1.21E-01 | 1.19E-01 | 3.76E-01 |
| SABOYETA | 0.0 | 10.00 | 0.0 | 2.27E+00 | 3.93E-03 | 3.33E-03 | 2.03E+00 | 8.55E-01 | 5.17E+00 |
| RANGE NORTH | 0.0 | 5.00 | 0.0 | 1.08E+01 | 1.87E-02 | 1.58E-02 | 9.67E+00 | 3.76E+00 | 2.43E+01 |
| RANGE EAST | -15.00 | 0.0 | 0.0 | 1.12E-01 | 1.93E-04 | 1.64E-04 | 9.98E-02 | 4.98E-02 | 2.62E-01 |
| RANGE WEST | -5.00 | 0.0 | 0.0 | 2.33E+00 | 4.02E-03 | 3.40E-03 | 2.08E+00 | 8.03E-01 | 5.21E+00 |
| RANGE SOUTH | 0.0 | -10.00 | 0.0 | 1.57E+01 | 2.72E-02 | 2.30E-02 | 1.40E+01 | 5.39E+00 | 3.52E+01 |

Table D.13. External Dose Commitments (mrem/yr)
to Whole Body from Ground Deposition

| IDENTIFICATION | X(KM) | Y(KM) | Z(M) | U238 | U234 | TH230 | RA226 | PB210 | TOTAL |
|---|---|---|---|---|---|---|---|---|---|
| ALBUQUERQUE | 60.00 | 0.0 | 0.0 | 1.33E-05 | 1.72E-06 | 2.20E-06 | 7.82E-04 | 3.40E-05 | 8.33E-04 |
| BIBO | -2.00 | 3.00 | 0.0 | 2.64E-02 | 3.41E-03 | 4.37E-03 | 1.55E+00 | 1.64E-02 | 1.60E+00 |
| BLUEWATER | -60.00 | 30.00 | 0.0 | 2.05E-05 | 2.65E-06 | 3.39E-06 | 1.21E-03 | 4.16E-05 | 1.28E-03 |
| BELEN | 50.00 | -40.00 | 0.0 | 1.19E-04 | 1.54E-05 | 1.97E-05 | 7.00E-03 | 1.85E-04 | 7.34E-03 |
| CASA BLANCA | -10.00 | -10.00 | 0.0 | 5.56E-03 | 7.19E-04 | 9.21E-04 | 3.28E-01 | 3.67E-03 | 3.33E-01 |
| CUBERO | -16.00 | -10.00 | 0.0 | 2.01E-03 | 2.60E-04 | 3.33E-04 | 1.18E-01 | 1.42E-03 | 1.22E-01 |
| GRANTS- MILLAN | -40.00 | 0.0 | 0.0 | 2.72E-05 | 3.51E-06 | 4.50E-06 | 1.60E-03 | 4.86E-05 | 1.68E-03 |
| JACKPILE-HOUSING | 0.0 | -0.20 | 0.0 | 4.62E-01 | 5.97E-02 | 7.65E-02 | 2.72E+01 | 2.84E-01 | 2.81E+01 |
| LAGUNA AND ENCINAL | -5.00 | 10.00 | 0.0 | 4.12E-03 | 5.32E-04 | 6.81E-04 | 2.42E-01 | 3.08E-03 | 2.51E-01 |
| LOS LUNAS | 60.00 | -30.00 | 0.0 | 4.77E-05 | 6.17E-06 | 7.90E-06 | 2.81E-03 | 8.46E-05 | 2.96E-03 |
| MESITA | 3.00 | -12.00 | 0.0 | 5.05E-02 | 6.53E-03 | 8.36E-03 | 2.97E+00 | 3.18E-02 | 3.07E+00 |
| MONITOR AT DUMP F | 2.70 | 0.0 | 20.00 | 3.44E-01 | 4.44E-02 | 5.69E-02 | 2.02E+01 | 2.11E-01 | 2.09E+01 |
| MONITOR AT WELL 4 | -0.70 | 2.30 | 1.00 | 6.05E-02 | 7.82E-03 | 1.00E-02 | 3.56E+00 | 3.73E-02 | 3.68E+00 |
| MONITOR AT WEST SIDE | -2.00 | 0.70 | 1.00 | 3.38E-01 | 4.36E-02 | 5.59E-02 | 1.99E+01 | 2.07E-01 | 2.05E+01 |
| MONITOR AT MINE VENT | -3.30 | -2.20 | 20.00 | 1.14E-01 | 1.47E-02 | 1.88E-02 | 6.70E+00 | 7.00E-02 | 6.91E+00 |
| MOQUINO | -1.50 | 5.00 | 0.0 | 2.05E-02 | 2.65E-03 | 3.39E-03 | 1.21E+00 | 1.31E-02 | 1.25E+00 |
| PAGUATE | 3.00 | 1.00 | 0.0 | 1.17E-01 | 1.51E-02 | 1.94E-02 | 6.90E+00 | 7.20E-02 | 7.12E+00 |
| SEAMA | -14.00 | -10.00 | 0.0 | 2.85E-03 | 3.69E-04 | 4.72E-04 | 1.68E-01 | 1.96E-03 | 1.73E-01 |
| SAN FIDEL | -25.00 | 0.0 | 0.0 | 7.70E-05 | 9.95E-06 | 1.27E-05 | 4.53E-03 | 8.85E-05 | 4.72E-03 |
| SAN MATEO | -20.00 | 30.00 | 0.0 | 3.33E-04 | 4.30E-05 | 5.51E-05 | 1.96E-02 | 5.31E-04 | 2.06E-02 |
| SABOYETA | 0.0 | 10.00 | 0.0 | 5.59E-03 | 7.23E-04 | 9.25E-04 | 3.29E-01 | 3.81E-03 | 3.40E-01 |
| RANGE NORTH | 0.0 | 5.00 | 0.0 | 2.66E-02 | 3.44E-03 | 4.40E-03 | 1.57E+00 | 1.68E-02 | 1.62E+00 |
| RANGE EAST | -15.00 | 0.0 | 0.0 | 2.75E-04 | 3.55E-05 | 4.55E-05 | 1.62E-02 | 2.22E-04 | 1.68E-02 |
| RANGE WEST | -5.00 | 0.0 | 0.0 | 5.72E-03 | 7.39E-04 | 9.46E-04 | 3.37E-01 | 3.50E-03 | 3.48E-01 |
| RANGE SOUTH | 0.0 | -10.00 | 0.0 | 3.86E-02 | 5.00E-03 | 6.40E-03 | 2.28E+00 | 2.41E-02 | 2.35E+00 |

Table D.14. External Dose Commitments (mrem/yr) to Ovaries from Ground Deposition

| IDENTIFICATION | X(KM) | Y(KM) | Z(M) | U238 | U234 | TH230 | RA226 | PB210 | TOTAL |
|---|---|---|---|---|---|---|---|---|---|
| ALBUQUERQUE | 60.00 | 0.0 | 0.0 | 7.00E-06 | 4.56E-07 | 9.34E-07 | 5.81E-04 | 1.80E-05 | 6.07E-04 |
| BIBO | -2.00 | 3.00 | 0.0 | 1.39E-02 | 9.06E-04 | 1.86E-03 | 1.15E+00 | 8.66E-03 | 1.18E+00 |
| BLUEWATER | -60.00 | 30.00 | 0.0 | 1.08E-05 | 7.04E-07 | 1.44E-06 | 8.97E-04 | 2.20E-05 | 9.31E-04 |
| BELEN | 50.00 | -40.00 | 0.0 | 6.27E-05 | 4.09E-06 | 8.37E-06 | 5.20E-03 | 9.77E-05 | 5.37E-03 |
| CASA BLANCA | -10.00 | -10.00 | 0.0 | 2.94E-03 | 1.91E-04 | 3.91E-04 | 2.43E-01 | 1.94E-03 | 2.49E-01 |
| CUBERO | -16.00 | -10.00 | 0.0 | 1.06E-03 | 6.90E-05 | 1.41E-04 | 8.78E-02 | 7.53E-04 | 8.98E-02 |
| GRANTS- MILLAN | -40.00 | 0.0 | 0.0 | 1.43E-05 | 9.33E-07 | 1.91E-06 | 1.19E-03 | 2.57E-05 | 1.23E-03 |
| JACKPILE-HOUSING | 0.0 | -0.20 | 0.0 | 2.44E-01 | 1.59E-02 | 3.25E-02 | 2.02E+01 | 1.50E-01 | 2.06E+01 |
| LAGUNA AND ENCINAL | -5.00 | 10.00 | 0.0 | 2.17E-03 | 1.41E-04 | 2.90E-04 | 1.80E-01 | 1.63E-03 | 1.84E-01 |
| LOS LUNAS | 60.00 | -30.00 | 0.0 | 2.52E-05 | 1.64E-06 | 3.36E-06 | 2.09E-03 | 4.47E-05 | 2.16E-03 |
| MESITA | 3.00 | -12.00 | 0.0 | 2.66E-02 | 1.74E-03 | 3.55E-03 | 2.21E+00 | 1.68E-02 | 2.26E+00 |
| MONITOR AT DUMP F | 2.70 | 0.0 | 20.00 | 1.81E-01 | 1.18E-02 | 2.42E-02 | 1.50E+01 | 1.12E-01 | 1.54E+01 |
| MONITOR AT WELL 4 | -0.70 | 2.30 | 1.00 | 3.19E-02 | 2.08E-03 | 4.25E-03 | 2.65E+00 | 1.97E-02 | 2.70E+00 |
| MONITOR AT WEST SIDE | -2.00 | 0.70 | 1.00 | 1.78E-01 | 1.16E-02 | 2.37E-02 | 1.48E+01 | 1.10E-01 | 1.51E+01 |
| MONITOR AT MINE VENT | -3.30 | -2.20 | 20.00 | 6.00E-02 | 3.91E-03 | 8.00E-03 | 4.97E+00 | 3.70E-02 | 5.03E+00 |
| MOQUINO | -1.50 | 5.00 | 0.0 | 1.08E-02 | 7.04E-04 | 1.44E-03 | 8.96E-01 | 6.91E-03 | 9.16E-01 |
| PAGUATE | 3.00 | 1.00 | 0.0 | 6.18E-02 | 4.02E-03 | 8.24E-03 | 5.12E+00 | 3.81E-02 | 5.23E+00 |
| SEAMA | -14.00 | -10.00 | 0.0 | 1.50E-03 | 9.79E-05 | 2.00E-04 | 1.25E-01 | 1.04E-03 | 1.27E-01 |
| SAN FIDEL | -25.00 | 0.0 | 0.0 | 4.06E-05 | 2.64E-06 | 5.41E-06 | 3.37E-03 | 4.68E-05 | 3.46E-03 |
| SAN MATEO | -20.00 | 30.00 | 0.0 | 1.76E-04 | 1.14E-05 | 2.34E-05 | 1.46E-02 | 2.81E-04 | 1.50E-02 |
| SABOYETA | 0.0 | 10.00 | 0.0 | 2.95E-03 | 1.92E-04 | 3.93E-04 | 2.44E-01 | 2.02E-03 | 2.50E-01 |
| RANGE NORTH | 0.0 | 5.00 | 0.0 | 1.40E-02 | 9.14E-04 | 1.87E-03 | 1.16E+00 | 8.87E-03 | 1.19E+00 |
| RANGE EAST | -15.00 | 0.0 | 0.0 | 1.45E-04 | 9.44E-06 | 1.93E-05 | 1.20E-02 | 1.17E-04 | 1.23E-02 |
| RANGE WEST | -5.00 | 0.0 | 0.0 | 3.02E-03 | 1.96E-04 | 4.02E-04 | 2.50E-01 | 1.90E-03 | 2.55E-01 |
| RANGE SOUTH | 0.0 | -10.00 | 0.0 | 2.04E-02 | 1.33E-03 | 2.72E-03 | 1.69E+00 | 1.27E-02 | 1.73E+00 |

Table D.15. External Dose Commitments (mrem/yr) to Testes from Ground Deposition

| IDENTIFICATION | X(KM) | Y(KM) | Z(M) | U238 | U234 | TH230 | RA226 | PB210 | TOTAL |
|---|---|---|---|---|---|---|---|---|---|
| ALBUQUERQUE | 60.00 | 0.0 | 0.0 | 1.17E-05 | 1.44E-06 | 1.94E-06 | 6.71E-04 | 2.88E-05 | 7.15E-04 |
| BIBO | -2.00 | 3.00 | 0.0 | 2.32E-02 | 2.85E-03 | 3.85E-03 | 1.33E+00 | 1.39E-02 | 1.38E+00 |
| BLUEWATER | -60.00 | 30.00 | 0.0 | 1.80E-05 | 2.22E-06 | 3.00E-06 | 1.04E-03 | 3.52E-05 | 1.09E-03 |
| BELEN | 50.00 | -40.00 | 0.0 | 1.05E-04 | 1.29E-05 | 1.74E-05 | 6.01E-03 | 1.56E-04 | 6.30E-03 |
| CASA BLANCA | -10.00 | -10.00 | 0.0 | 4.89E-03 | 6.02E-04 | 8.13E-04 | 2.81E-01 | 3.10E-03 | 2.91E-01 |
| CUBERO | -16.00 | -10.00 | 0.0 | 1.77E-03 | 2.17E-04 | 2.93E-04 | 1.02E-01 | 1.20E-03 | 1.05E-01 |
| GRANTS- MILLAN | -40.00 | 0.0 | 0.0 | 2.39E-05 | 2.94E-06 | 3.97E-06 | 1.37E-03 | 4.11E-05 | 1.45E-03 |
| JACKPILE-HOUSING | 0.0 | -0.20 | 0.0 | 4.06E-01 | 5.00E-02 | 6.75E-02 | 2.34E+01 | 2.40E-01 | 2.41E+01 |
| LAGUNA AND ENCINAL | -5.00 | 10.00 | 0.0 | 3.62E-03 | 4.45E-04 | 6.01E-04 | 2.08E-01 | 2.61E-03 | 2.15E-01 |
| LOS LUNAS | 60.00 | -30.00 | 0.0 | 4.20E-05 | 5.17E-06 | 6.97E-06 | 2.41E-03 | 7.15E-05 | 2.54E-03 |
| MESITA | 3.00 | -12.00 | 0.0 | 4.44E-02 | 5.47E-03 | 7.38E-03 | 2.55E+00 | 2.69E-02 | 2.64E+00 |
| MONITOR AT DUMP F | 2.70 | 0.0 | 20.00 | 3.02E-01 | 3.72E-02 | 5.02E-02 | 1.74E+01 | 1.79E-01 | 1.79E+01 |
| MONITOR AT WELL 4 | -0.70 | 2.30 | 1.00 | 5.32E-02 | 6.55E-03 | 8.84E-03 | 3.06E+00 | 3.16E-02 | 3.16E+00 |
| MONITOR AT WEST SIDE | -2.00 | 0.70 | 1.00 | 2.97E-01 | 3.65E-02 | 4.93E-02 | 1.71E+01 | 1.75E-01 | 1.76E+01 |
| MONITOR AT MINE VENT | -3.30 | -2.20 | 20.00 | 1.00E-01 | 1.23E-02 | 1.66E-02 | 5.75E+00 | 5.92E-02 | 5.94E+00 |
| MOQUINO | -1.50 | 5.00 | 0.0 | 1.80E-02 | 2.22E-03 | 2.99E-03 | 1.04E+00 | 1.11E-02 | 1.07E+00 |
| PAGUATE | 3.00 | 1.00 | 0.0 | 1.03E-01 | 1.27E-02 | 1.71E-02 | 5.92E+00 | 6.09E-02 | 6.12E+00 |
| SEAMA | -14.00 | -10.00 | 0.0 | 2.51E-03 | 3.08E-04 | 4.16E-04 | 1.44E-01 | 1.66E-03 | 1.49E-01 |
| SAN FIDEL | -25.00 | 0.0 | 0.0 | 6.77E-05 | 8.33E-06 | 1.12E-05 | 3.89E-03 | 7.48E-05 | 4.05E-03 |
| SAN MATEO | -20.00 | 30.00 | 0.0 | 2.93E-04 | 3.60E-05 | 4.86E-05 | 1.68E-02 | 4.49E-04 | 1.77E-02 |
| SABOYETA | 0.0 | 10.00 | 0.0 | 4.91E-03 | 6.05E-04 | 8.16E-04 | 2.83E-01 | 3.23E-03 | 2.92E-01 |
| RANGE NORTH | 0.0 | 5.00 | 0.0 | 2.34E-02 | 2.88E-03 | 3.89E-03 | 1.34E+00 | 1.42E-02 | 1.39E+00 |
| RANGE EAST | -15.00 | 0.0 | 0.0 | 2.42E-04 | 2.97E-05 | 4.01E-05 | 1.39E-02 | 1.83E-04 | 1.44E-02 |
| RANGE WEST | -5.00 | 0.0 | 0.0 | 5.03E-03 | 6.19E-04 | 8.35E-04 | 2.89E-01 | 3.03E-03 | 2.99E-01 |
| RANGE SOUTH | 0.0 | -10.00 | 0.0 | 3.40E-02 | 4.18E-03 | 5.65E-03 | 1.95E+00 | 2.04E-02 | 2.02E+00 |

Table D.16. External Dose Commitments (mrem/yr) to Lung from Ground Deposition

| IDENTIFICATION | X(KM) | Y(KM) | Z(M) | U238 | U234 | TH230 | RA226 | PB210 | TOTAL |
|---|---|---|---|---|---|---|---|---|---|
| ALBUQUERQUE | 60.00 | 0.0 | 0.0 | 1.10E-05 | 7.08E-07 | 1.29E-06 | 7.39E-04 | 2.16E-05 | 7.74E-04 |
| BIBO | -2.00 | 3.00 | 0.0 | 2.19E-02 | 1.41E-03 | 2.56E-03 | 1.47E+00 | 1.04E-02 | 1.50E+00 |
| BLUEWATER | -60.00 | 30.00 | 0.0 | 1.70E-05 | 1.09E-06 | 1.99E-06 | 1.14E-03 | 2.64E-05 | 1.19E-03 |
| BELEN | 50.00 | -40.00 | 0.0 | 9.87E-05 | 6.34E-06 | 1.16E-05 | 6.62E-03 | 1.17E-04 | 6.85E-03 |
| CASA BLANCA | -10.00 | -10.00 | 0.0 | 4.62E-03 | 2.97E-04 | 5.40E-04 | 3.10E-01 | 2.33E-03 | 3.17E-01 |
| CUBERO | -16.00 | -10.00 | 0.0 | 1.67E-03 | 1.07E-04 | 1.95E-04 | 1.12E-01 | 9.03E-04 | 1.15E-01 |
| GRANTS- MILLAN | -40.00 | 0.0 | 0.0 | 2.25E-05 | 1.45E-06 | 2.64E-06 | 1.51E-03 | 3.09E-05 | 1.57E-03 |
| JACKPILE-HOUSING | 0.0 | -0.20 | 0.0 | 3.83E-01 | 2.46E-02 | 4.49E-02 | 2.57E+01 | 1.80E-01 | 2.63E+01 |
| LAGUNA AND ENCINAL | -5.00 | 10.00 | 0.0 | 3.41E-03 | 2.19E-04 | 4.00E-04 | 2.29E-01 | 1.95E-03 | 2.35E-01 |
| LOS LUNAS | 60.00 | -30.00 | 0.0 | 3.96E-05 | 2.54E-06 | 4.64E-06 | 2.66E-03 | 5.36E-05 | 2.76E-03 |
| MESITA | 3.00 | -12.00 | 0.0 | 4.19E-02 | 2.69E-03 | 4.91E-03 | 2.81E+00 | 2.02E-02 | 2.88E+00 |
| MONITOR AT DUMP F | 2.70 | 0.0 | 20.00 | 2.85E-01 | 1.83E-02 | 3.34E-02 | 1.91E+01 | 1.34E-01 | 1.96E+01 |
| MONITOR AT WELL 4 | -0.70 | 2.30 | 1.00 | 5.02E-02 | 3.22E-03 | 5.87E-03 | 3.37E+00 | 2.37E-02 | 3.45E+00 |
| MONITOR AT WEST SIDE | -2.00 | 0.70 | 1.00 | 2.80E-01 | 1.80E-02 | 3.28E-02 | 1.88E+01 | 1.31E-01 | 1.92E+01 |
| MONITOR AT MINE VENT | -3.30 | -2.20 | 20.00 | 9.43E-02 | 6.06E-03 | 1.10E-02 | 6.33E+00 | 4.44E-02 | 6.49E+00 |
| MOQUINO | -1.50 | 5.00 | 0.0 | 1.70E-02 | 1.09E-03 | 1.99E-03 | 1.14E+00 | 8.29E-03 | 1.17E+00 |
| PAGUATE | 3.00 | 1.00 | 0.0 | 9.72E-02 | 6.24E-03 | 1.14E-02 | 6.52E+00 | 4.57E-02 | 6.68E+00 |
| SEAMA | -14.00 | -10.00 | 0.0 | 2.36E-03 | 1.52E-04 | 2.77E-04 | 1.59E-01 | 1.24E-03 | 1.63E-01 |
| SAN FIDEL | -25.00 | 0.0 | 0.0 | 6.39E-05 | 4.10E-06 | 7.48E-06 | 4.28E-03 | 5.61E-05 | 4.42E-03 |
| SAN MATEO | -20.00 | 30.00 | 0.0 | 2.76E-04 | 1.77E-05 | 3.23E-05 | 1.85E-02 | 3.37E-04 | 1.92E-02 |
| SABOYETA | 0.0 | 10.00 | 0.0 | 4.64E-03 | 2.98E-04 | 5.43E-04 | 3.11E-01 | 2.42E-03 | 3.19E-01 |
| RANGE NORTH | 0.0 | 5.00 | 0.0 | 2.21E-02 | 1.42E-03 | 2.58E-03 | 1.48E+00 | 1.06E-02 | 1.52E+00 |
| RANGE EAST | -15.00 | 0.0 | 0.0 | 2.28E-04 | 1.46E-05 | 2.67E-05 | 1.53E-02 | 1.41E-04 | 1.57E-02 |
| RANGE WEST | -5.00 | 0.0 | 0.0 | 4.74E-03 | 3.05E-04 | 5.55E-04 | 3.18E-01 | 2.27E-03 | 3.26E-01 |
| RANGE SOUTH | 0.0 | -10.00 | 0.0 | 3.21E-02 | 2.06E-03 | 3.75E-03 | 2.15E+00 | 1.53E-02 | 2.20E+00 |

Table D.17. External Dose Commitments (mrem/yr)
to Red Marrow from Ground Deposition

| IDENTIFICATION | X(KM) | Y(KM) | Z(M) | U238 | U234 | TH230 | RA226 | PB210 | TOTAL |
|---|---|---|---|---|---|---|---|---|---|
| ALBUQUERQUE | 60.00 | 0.0 | 0.0 | 1.71E-05 | 1.81E-06 | 2.96E-06 | 8.26E-04 | 5.34E-05 | 9.02E-04 |
| BIBO | -2.00 | 3.00 | 0.0 | 3.40E-02 | 3.60E-03 | 5.83E-03 | 1.64E+00 | 2.57E-02 | 1.71E+00 |
| BLUEWATER | -60.00 | 30.00 | 0.0 | 2.64E-05 | 2.80E-06 | 4.57E-06 | 1.28E-03 | 6.52E-05 | 1.37E-03 |
| BELEN | 50.00 | -40.00 | 0.0 | 1.53E-04 | 1.62E-05 | 2.65E-05 | 7.40E-03 | 2.90E-04 | 7.89E-03 |
| CASA BLANCA | -10.00 | -10.00 | 0.0 | 7.17E-03 | 7.60E-04 | 1.24E-03 | 3.46E-01 | 5.76E-03 | 3.61E-01 |
| CUBERO | -16.00 | -10.00 | 0.0 | 2.59E-03 | 2.74E-04 | 4.48E-04 | 1.25E-01 | 2.23E-03 | 1.31E-01 |
| GRANTS- MILLAN | -40.00 | 0.0 | 0.0 | 3.50E-05 | 3.71E-06 | 6.06E-06 | 1.69E-03 | 7.63E-05 | 1.81E-03 |
| JACKPILE-HOUSING | 0.0 | -0.20 | 0.0 | 5.95E-01 | 6.31E-02 | 1.03E-01 | 2.87E+01 | 4.45E-01 | 2.99E+01 |
| LAGUNA AND ENCINAL | -5.00 | 10.00 | 0.0 | 5.30E-03 | 5.62E-04 | 9.18E-04 | 2.56E-01 | 4.83E-03 | 2.68E-01 |
| LOS LUNAS | 60.00 | -30.00 | 0.0 | 6.15E-05 | 6.52E-06 | 1.06E-05 | 2.97E-03 | 1.33E-04 | 3.18E-03 |
| MESITA | 3.00 | -12.00 | 0.0 | 6.51E-02 | 6.90E-03 | 1.13E-02 | 3.14E+00 | 4.99E-02 | 3.28E+00 |
| MONITOR AT DUMP F | 2.70 | 0.0 | 20.00 | 4.43E-01 | 4.69E-02 | 7.66E-02 | 2.14E+01 | 3.31E-01 | 2.23E+01 |
| MONITOR AT WELL 4 | -0.70 | 2.30 | 1.00 | 7.79E-02 | 8.26E-03 | 1.35E-02 | 3.76E+00 | 5.85E-02 | 3.92E+00 |
| MONITOR AT WEST SIDE | -2.00 | 0.70 | 1.00 | 4.35E-01 | 4.61E-02 | 7.52E-02 | 2.10E+01 | 3.25E-01 | 2.19E+01 |
| MONITOR AT MINE VENT | -3.30 | -2.20 | 20.00 | 1.47E-01 | 1.55E-02 | 2.54E-02 | 7.08E+00 | 1.10E-01 | 7.38E+00 |
| MOQUINO | -1.50 | 5.00 | 0.0 | 2.64E-02 | 2.80E-03 | 4.57E-03 | 1.28E+00 | 2.05E-02 | 1.33E+00 |
| PAGUATE | 3.00 | 1.00 | 0.0 | 1.51E-01 | 1.60E-02 | 2.61E-02 | 7.29E+00 | 1.13E-01 | 7.60E+00 |
| SEAMA | -14.00 | -10.00 | 0.0 | 3.67E-03 | 3.89E-04 | 6.35E-04 | 1.77E-01 | 3.08E-03 | 1.85E-01 |
| SAN FIDEL | -25.00 | 0.0 | 0.0 | 9.92E-05 | 1.05E-05 | 1.72E-05 | 4.79E-03 | 1.39E-04 | 5.06E-03 |
| SAN MATEO | -20.00 | 30.00 | 0.0 | 4.29E-04 | 4.55E-05 | 7.42E-05 | 2.07E-02 | 8.32E-04 | 2.21E-02 |
| SABOYETA | 0.0 | 10.00 | 0.0 | 7.20E-03 | 7.64E-04 | 1.25E-03 | 3.48E-01 | 5.98E-03 | 3.63E-01 |
| RANGE NORTH | 0.0 | 5.00 | 0.0 | 3.43E-02 | 3.63E-03 | 5.93E-03 | 1.66E+00 | 2.63E-02 | 1.73E+00 |
| RANGE EAST | -15.00 | 0.0 | 0.0 | 3.54E-04 | 3.75E-05 | 6.12E-05 | 1.71E-02 | 3.49E-04 | 1.79E-02 |
| RANGE WEST | -5.00 | 0.0 | 0.0 | 7.37E-03 | 7.81E-04 | 1.27E-03 | 3.56E-01 | 5.62E-03 | 3.71E-01 |
| RANGE SOUTH | 0.0 | -10.00 | 0.0 | 4.98E-02 | 5.28E-03 | 8.61E-03 | 2.40E+00 | 3.77E-02 | 2.51E+00 |

Table D.18. External Dose Commitments (mrem/yr) to Skin from Cloud Submersion

| IDENTIFICATION | X(KM) | Y(KM) | Z(M) | U238 | U234 | TH230 | RA226 | PB210-RN222 | TOTAL |
|---|---|---|---|---|---|---|---|---|---|
| ALBUQUERQUE | 60.00 | 0.0 | 0.0 | 4.28E-09 | 6.97E-11 | 7.48E-11 | 1.26E-08 | 3.19E-03 | 3.19E-03 |
| BIBO | -2.00 | 3.00 | 0.0 | 1.76E-06 | 2.86E-08 | 3.07E-08 | 5.17E-06 | 5.71E-01 | 5.71E-01 |
| BLUEWATER | -60.00 | 30.00 | 0.0 | 6.22E-09 | 1.01E-10 | 1.09E-10 | 1.83E-08 | 3.26E-03 | 3.26E-03 |
| BELEN | 50.00 | -40.00 | 0.0 | 3.35E-08 | 5.46E-10 | 5.86E-10 | 9.86E-08 | 1.29E-02 | 1.29E-02 |
| CASA BLANCA | -10.00 | -10.00 | 0.0 | 6.18E-07 | 1.01E-08 | 1.08E-08 | 1.82E-06 | 1.32E-01 | 1.32E-01 |
| CUBERO | -16.00 | -10.00 | 0.0 | 2.77E-07 | 4.50E-09 | 4.84E-09 | 8.14E-07 | 7.47E-02 | 7.47E-02 |
| GRANTS- MILLAN | -40.00 | 0.0 | 0.0 | 8.06E-09 | 1.31E-10 | 1.41E-10 | 2.37E-08 | 5.93E-03 | 5.93E-03 |
| JACKPILE-HOUSING | 0.0 | -0.20 | 0.0 | 1.57E-05 | 2.56E-07 | 2.75E-07 | 4.63E-05 | 7.20E-01 | 7.20E-01 |
| LAGUNA AND ENCINAL | -5.00 | 10.00 | 0.0 | 5.63E-07 | 9.17E-09 | 9.85E-09 | 1.66E-06 | 4.03E-01 | 4.03E-01 |
| LOS LUNAS | 60.00 | -30.00 | 0.0 | 1.44E-08 | 2.34E-10 | 2.51E-10 | 4.23E-08 | 6.48E-03 | 6.48E-03 |
| MESITA | 3.00 | -12.00 | 0.0 | 4.95E-06 | 8.05E-08 | 8.65E-08 | 1.46E-05 | 5.10E-01 | 5.10E-01 |
| MONITOR AT DUMP F | 2.70 | 0.0 | 20.00 | 1.33E-05 | 2.17E-07 | 2.33E-07 | 3.92E-05 | 6.94E-01 | 6.94E-01 |
| MONITOR AT WELL 4 | -0.70 | 2.30 | 1.00 | 3.43E-06 | 5.58E-08 | 5.99E-08 | 1.01E-05 | 8.38E-01 | 8.38E-01 |
| MONITOR AT WEST SIDE | -2.00 | 0.70 | 1.00 | 8.97E-06 | 1.46E-07 | 1.57E-07 | 2.64E-05 | 3.75E-01 | 3.75E-01 |
| MONITOR AT MINE VENT | -3.30 | -2.20 | 20.00 | 5.61E-06 | 9.13E-08 | 9.80E-08 | 1.65E-05 | 4.87E-01 | 4.87E-01 |
| MOQUINO | -1.50 | 5.00 | 0.0 | 1.84E-06 | 2.99E-08 | 3.21E-08 | 5.41E-06 | 9.68E-01 | 9.68E-01 |
| PAGUATE | 3.00 | 1.00 | 0.0 | 5.72E-06 | 9.32E-08 | 1.00E-07 | 1.68E-05 | 4.63E-01 | 4.63E-01 |
| SEAMA | -14.00 | -10.00 | 0.0 | 3.65E-07 | 5.95E-09 | 6.39E-09 | 1.08E-06 | 9.05E-02 | 9.05E-02 |
| SAN FIDEL | -25.00 | 0.0 | 0.0 | 1.89E-08 | 3.07E-10 | 3.30E-10 | 5.55E-08 | 1.25E-02 | 1.25E-02 |
| SAN MATEO | -20.00 | 30.00 | 0.0 | 8.10E-08 | 1.32E-09 | 1.42E-09 | 2.38E-07 | 6.50E-02 | 6.50E-02 |
| SABOYETA | 0.0 | 10.00 | 0.0 | 7.42E-07 | 1.21E-08 | 1.30E-08 | 2.18E-06 | 3.49E-01 | 3.49E-01 |
| RANGE NORTH | 0.0 | 5.00 | 0.0 | 2.41E-06 | 3.93E-08 | 4.21E-08 | 7.09E-06 | 1.07E+00 | 1.07E+00 |
| RANGE EAST | -15.00 | 0.0 | 0.0 | 4.97E-08 | 8.10E-10 | 8.69E-10 | 1.46E-07 | 2.77E-02 | 2.77E-02 |
| RANGE WEST | -5.00 | 0.0 | 0.0 | 4.74E-07 | 7.72E-09 | 8.28E-09 | 1.39E-06 | 1.43E-01 | 1.43E-01 |
| RANGE SOUTH | 0.0 | -10.00 | 0.0 | 3.30E-06 | 5.38E-08 | 5.77E-08 | 9.72E-06 | 2.78E-01 | 2.78E-01 |

Table D.19. External Dose Commitments (mrem/yr)
to Whole Body from Cloud Submersion

| IDENTIFICATION | X(KM) | Y(KM) | Z(M) | U238 | U234 | TH230 | RA226 | PB210-RN222 | TOTAL |
|---|---|---|---|---|---|---|---|---|---|
| ALBUQUERQUE | 60.00 | 0.0 | 0.0 | 9.01E-11 | 1.28E-12 | 1.84E-12 | 6.82E-09 | 8.69E-04 | 8.69E-04 |
| BIBO | -2.00 | 3.00 | 0.0 | 3.70E-08 | 5.24E-10 | 7.56E-10 | 2.80E-06 | 1.51E-01 | 1.51E-01 |
| BLUEWATER | -60.00 | 30.00 | 0.0 | 1.31E-10 | 1.86E-12 | 2.68E-12 | 9.93E-09 | 8.88E-04 | 8.88E-04 |
| BELEN | 50.00 | -40.00 | 0.0 | 7.06E-10 | 9.99E-12 | 1.44E-11 | 5.34E-08 | 3.50E-03 | 3.50E-03 |
| CASA BLANCA | -10.00 | -10.00 | 0.0 | 1.30E-08 | 1.84E-10 | 2.65E-10 | 9.85E-07 | 3.57E-02 | 3.57E-02 |
| CUBERO | -16.00 | -10.00 | 0.0 | 5.83E-09 | 8.25E-11 | 1.19E-10 | 4.41E-07 | 2.02E-02 | 2.02E-02 |
| GRANTS- MILLAN | -40.00 | 0.0 | 0.0 | 1.70E-10 | 2.40E-12 | 3.46E-12 | 1.29E-08 | 1.61E-03 | 1.61E-03 |
| JACKPILE-HOUSING | 0.0 | -0.20 | 0.0 | 3.31E-07 | 4.69E-09 | 6.76E-09 | 2.51E-05 | 1.80E-01 | 1.80E-01 |
| LAGUNA AND ENCINAL | -5.00 | 10.00 | 0.0 | 1.19E-08 | 1.68E-10 | 2.42E-10 | 8.99E-07 | 1.09E-01 | 1.09E-01 |
| LOS LUNAS | 60.00 | -30.00 | 0.0 | 3.03E-10 | 4.28E-12 | 6.18E-12 | 2.29E-08 | 1.76E-03 | 1.76E-03 |
| MESITA | 3.00 | -12.00 | 0.0 | 1.04E-07 | 1.47E-09 | 2.13E-09 | 7.89E-06 | 1.38E-01 | 1.38E-01 |
| MONITOR AT DUMP F | 2.70 | 0.0 | 20.00 | 2.80E-07 | 3.97E-09 | 5.72E-09 | 2.12E-05 | 1.77E-01 | 1.77E-01 |
| MONITOR AT WELL 4 | -0.70 | 2.30 | 1.00 | 7.22E-08 | 1.02E-09 | 1.47E-09 | 5.47E-06 | 2.19E-01 | 2.19E-01 |
| MONITOR AT WEST SIDE | -2.00 | 0.70 | 1.00 | 1.89E-07 | 2.67E-09 | 3.85E-09 | 1.43E-05 | 9.45E-02 | 9.45E-02 |
| MONITOR AT MINE VENT | -3.30 | -2.20 | 20.00 | 1.18E-07 | 1.67E-09 | 2.41E-09 | 8.94E-06 | 1.29E-01 | 1.29E-01 |
| MOQUINO | -1.50 | 5.00 | 0.0 | 3.87E-08 | 5.48E-10 | 7.90E-10 | 2.93E-06 | 2.59E-01 | 2.59E-01 |
| PAGUATE | 3.00 | 1.00 | 0.0 | 1.21E-07 | 1.71E-09 | 2.46E-09 | 9.13E-06 | 1.19E-01 | 1.19E-01 |
| SEAMA | -14.00 | -10.00 | 0.0 | 7.70E-09 | 1.09E-10 | 1.57E-10 | 5.83E-07 | 2.45E-02 | 2.45E-02 |
| SAN FIDEL | -25.00 | 0.0 | 0.0 | 3.98E-10 | 5.63E-12 | 8.11E-12 | 3.01E-08 | 3.39E-03 | 3.39E-03 |
| SAN MATEO | -20.00 | 30.00 | 0.0 | 1.71E-09 | 2.41E-11 | 3.48E-11 | 1.29E-07 | 1.77E-02 | 1.77E-02 |
| SABOYETA | 0.0 | 10.00 | 0.0 | 1.56E-08 | 2.21E-10 | 3.19E-10 | 1.18E-06 | 9.41E-02 | 9.41E-02 |
| RANGE NORTH | 0.0 | 5.00 | 0.0 | 5.08E-08 | 7.19E-10 | 1.04E-09 | 3.85E-06 | 2.87E-01 | 2.87E-01 |
| RANGE EAST | -15.00 | 0.0 | 0.0 | 1.05E-09 | 1.48E-11 | 2.14E-11 | 7.93E-08 | 7.49E-03 | 7.49E-03 |
| RANGE WEST | -5.00 | 0.0 | 0.0 | 9.98E-09 | 1.41E-10 | 2.04E-10 | 7.56E-07 | 3.81E-02 | 3.81E-02 |
| RANGE SOUTH | 0.0 | -10.00 | 0.0 | 6.96E-08 | 9.85E-10 | 1.42E-09 | 5.27E-06 | 7.49E-02 | 7.49E-02 |

## Table D.20. External Dose Commitments (mrem/yr) to Ovaries from Cloud Submersion

| IDENTIFICATION | X(KM) | Y(KM) | Z(M) | U238 | U234 | TH230 | RA226 | PB210-RN222 | TOTAL |
|---|---|---|---|---|---|---|---|---|---|
| ALBUQUERQUE | 60.00 | 0.0 | 0.0 | 6.08E-11 | 3.40E-13 | 7.79E-13 | 5.07E-09 | 6.47E-04 | 6.47E-04 |
| BIBO | -2.00 | 3.00 | 0.0 | 2.50E-08 | 1.40E-10 | 3.20E-10 | 2.08E-06 | 1.10E-01 | 1.10E-01 |
| BLUEWATER | -60.00 | 30.00 | 0.0 | 8.85E-11 | 4.95E-13 | 1.13E-12 | 7.38E-09 | 6.61E-04 | 6.61E-04 |
| BELEN | 50.00 | -40.00 | 0.0 | 4.77E-10 | 2.66E-12 | 6.10E-12 | 3.97E-08 | 2.61E-03 | 2.61E-03 |
| CASA BLANCA | -10.00 | -10.00 | 0.0 | 8.78E-09 | 4.91E-11 | 1.12E-10 | 7.32E-07 | 2.65E-02 | 2.65E-02 |
| CUBERO | -16.00 | -10.00 | 0.0 | 3.93E-09 | 2.20E-11 | 5.03E-11 | 3.28E-07 | 1.50E-02 | 1.50E-02 |
| GRANTS- MILLAN | -40.00 | 0.0 | 0.0 | 1.15E-10 | 6.41E-13 | 1.47E-12 | 9.55E-09 | 1.20E-03 | 1.20E-03 |
| JACKPILE-HOUSING | 0.0 | -0.20 | 0.0 | 2.24E-07 | 1.25E-09 | 2.86E-09 | 1.86E-05 | 1.26E-01 | 1.26E-01 |
| LAGUNA AND ENCINAL | -5.00 | 10.00 | 0.0 | 8.01E-09 | 4.48E-11 | 1.03E-10 | 6.68E-07 | 8.07E-02 | 8.07E-02 |
| LOS LUNAS | 60.00 | -30.00 | 0.0 | 2.04E-10 | 1.14E-12 | 2.62E-12 | 1.70E-08 | 1.31E-03 | 1.31E-03 |
| MESITA | 3.00 | -12.00 | 0.0 | 7.04E-08 | 3.93E-10 | 9.00E-10 | 5.87E-06 | 1.02E-01 | 1.02E-01 |
| MONITOR AT DUMP F | 2.70 | 0.0 | 20.00 | 1.89E-07 | 1.06E-09 | 2.42E-09 | 1.58E-05 | 1.25E-01 | 1.25E-01 |
| MONITOR AT WELL 4 | -0.70 | 2.30 | 1.00 | 4.88E-08 | 2.73E-10 | 6.24E-10 | 4.06E-06 | 1.58E-01 | 1.58E-01 |
| MONITOR AT WEST SIDE | -2.00 | 0.70 | 1.00 | 1.28E-07 | 7.13E-10 | 1.63E-09 | 1.06E-05 | 6.64E-02 | 6.64E-02 |
| MONITOR AT MINE VENT | -3.30 | -2.20 | 20.00 | 7.97E-08 | 4.46E-10 | 1.02E-09 | 6.65E-06 | 9.40E-02 | 9.40E-02 |
| MOQUINO | -1.50 | 5.00 | 0.0 | 2.61E-08 | 1.46E-10 | 3.34E-10 | 2.18E-06 | 1.91E-01 | 1.91E-01 |
| PAGUATE | 3.00 | 1.00 | 0.0 | 8.14E-08 | 4.55E-10 | 1.04E-09 | 6.78E-06 | 8.53E-02 | 8.53E-02 |
| SEAMA | -14.00 | -10.00 | 0.0 | 5.20E-09 | 2.90E-11 | 6.65E-11 | 4.33E-07 | 1.82E-02 | 1.82E-02 |
| SAN FIDEL | -25.00 | 0.0 | 0.0 | 2.68E-10 | 1.50E-12 | 3.44E-12 | 2.24E-08 | 2.52E-03 | 2.52E-03 |
| SAN MATEO | -20.00 | 30.00 | 0.0 | 1.15E-09 | 6.44E-12 | 1.47E-11 | 9.60E-08 | 1.31E-02 | 1.31E-02 |
| SABOYETA | 0.0 | 10.00 | 0.0 | 1.06E-08 | 5.90E-11 | 1.35E-10 | 8.80E-07 | 6.96E-02 | 6.96E-02 |
| RANGE NORTH | 0.0 | 5.00 | 0.0 | 3.43E-08 | 1.92E-10 | 4.39E-10 | 2.86E-06 | 2.10E-01 | 2.10E-01 |
| RANGE EAST | -15.00 | 0.0 | 0.0 | 7.07E-10 | 3.95E-12 | 9.05E-12 | 5.90E-08 | 5.55E-03 | 5.55E-03 |
| RANGE WEST | -5.00 | 0.0 | 0.0 | 6.74E-09 | 3.77E-11 | 8.62E-11 | 5.62E-07 | 2.80E-02 | 2.80E-02 |
| RANGE SOUTH | 0.0 | -10.00 | 0.0 | 4.70E-08 | 2.63E-10 | 6.01E-10 | 3.92E-06 | 5.54E-02 | 5.54E-02 |

Table D.21. External Dose Commitments (mrem/yr)
to Testes from Cloud Submersion

| IDENTIFICATION | X(KM) | Y(KM) | Z(M) | U238 | U234 | TH230 | RA226 | PB210-RN222 | TOTAL |
|---|---|---|---|---|---|---|---|---|---|
| ALBUQUERQUE | 60.00 | 0.0 | 0.0 | 6.68E-11 | 1.07E-12 | 1.62E-12 | 5.79E-09 | 7.36E-04 | 7.36E-04 |
| BIBO | -2.00 | 3.00 | 0.0 | 2.74E-08 | 4.40E-10 | 6.67E-10 | 2.38E-06 | 1.30E-01 | 1.30E-01 |
| BLUEWATER | -60.00 | 30.00 | 0.0 | 9.72E-11 | 1.56E-12 | 2.36E-12 | 8.42E-09 | 7.52E-04 | 7.52E-04 |
| BELEN | 50.00 | -40.00 | 0.0 | 5.23E-10 | 8.38E-12 | 1.27E-11 | 4.53E-08 | 2.96E-03 | 2.96E-03 |
| CASA BLANCA | -10.00 | -10.00 | 0.0 | 9.64E-09 | 1.55E-10 | 2.34E-10 | 8.35E-07 | 3.03E-02 | 3.03E-02 |
| CUBERO | -16.00 | -10.00 | 0.0 | 4.32E-09 | 6.92E-11 | 1.05E-10 | 3.74E-07 | 1.72E-02 | 1.72E-02 |
| GRANTS- MILLAN | -40.00 | 0.0 | 0.0 | 1.26E-10 | 2.02E-12 | 3.06E-12 | 1.09E-08 | 1.36E-03 | 1.36E-03 |
| JACKPILE-HOUSING | 0.0 | -0.20 | 0.0 | 2.45E-07 | 3.93E-09 | 5.97E-09 | 2.13E-05 | 1.61E-01 | 1.61E-01 |
| LAGUNA AND ENCINAL | -5.00 | 10.00 | 0.0 | 8.80E-09 | 1.41E-10 | 2.14E-10 | 7.62E-07 | 9.26E-02 | 9.26E-02 |
| LOS LUNAS | 60.00 | -30.00 | 0.0 | 2.24E-10 | 3.60E-12 | 5.45E-12 | 1.94E-08 | 1.49E-03 | 1.49E-03 |
| MESITA | 3.00 | -12.00 | 0.0 | 7.72E-08 | 1.24E-09 | 1.88E-09 | 6.69E-06 | 1.17E-01 | 1.17E-01 |
| MONITOR AT DUMP F | 2.70 | 0.0 | 20.00 | 2.08E-07 | 3.33E-09 | 5.05E-09 | 1.80E-05 | 1.56E-01 | 1.56E-01 |
| MONITOR AT WELL 4 | -0.70 | 2.30 | 1.00 | 5.35E-08 | 8.58E-10 | 1.30E-09 | 4.64E-06 | 1.90E-01 | 1.90E-01 |
| MONITOR AT WEST SIDE | -2.00 | 0.70 | 1.00 | 1.40E-07 | 2.24E-09 | 3.40E-09 | 1.21E-05 | 8.41E-02 | 8.41E-02 |
| MONITOR AT MINE VENT | -3.30 | -2.20 | 20.00 | 8.75E-08 | 1.40E-09 | 2.13E-09 | 7.58E-06 | 1.11E-01 | 1.11E-01 |
| MOQUINO | -1.50 | 5.00 | 0.0 | 2.87E-08 | 4.60E-10 | 6.97E-10 | 2.48E-06 | 2.22E-01 | 2.22E-01 |
| PAGUATE | 3.00 | 1.00 | 0.0 | 8.93E-08 | 1.43E-09 | 2.17E-09 | 7.74E-06 | 1.04E-01 | 1.04E-01 |
| SEAMA | -14.00 | -10.00 | 0.0 | 5.70E-09 | 9.14E-11 | 1.39E-10 | 4.94E-07 | 2.08E-02 | 2.08E-02 |
| SAN FIDEL | -25.00 | 0.0 | 0.0 | 2.95E-10 | 4.72E-12 | 7.16E-12 | 2.55E-08 | 2.88E-03 | 2.88E-03 |
| SAN MATEO | -20.00 | 30.00 | 0.0 | 1.26E-09 | 2.03E-11 | 3.07E-11 | 1.10E-07 | 1.50E-02 | 1.50E-02 |
| SABOYETA | 0.0 | 10.00 | 0.0 | 1.16E-08 | 1.86E-10 | 2.82E-10 | 1.00E-06 | 8.01E-02 | 8.01E-02 |
| RANGE NORTH | 0.0 | 5.00 | 0.0 | 3.76E-08 | 6.03E-10 | 9.15E-10 | 3.26E-06 | 2.46E-01 | 2.46E-01 |
| RANGE EAST | -15.00 | 0.0 | 0.0 | 7.76E-10 | 1.24E-11 | 1.89E-11 | 6.73E-08 | 6.37E-03 | 6.37E-03 |
| RANGE WEST | -5.00 | 0.0 | 0.0 | 7.40E-09 | 1.19E-10 | 1.80E-10 | 6.41E-07 | 3.27E-02 | 3.27E-02 |
| RANGE SOUTH | 0.0 | -10.00 | 0.0 | 5.16E-08 | 8.26E-10 | 1.25E-09 | 4.47E-06 | 6.38E-02 | 6.38E-02 |

Table D.22. External Dose Commitments (mrem/yr) to Lung from Cloud Submersion

| IDENTIFICATION | X(KM) | Y(KM) | Z(M) | U238 | U234 | TH230 | RA226 | PB210-RN222 | TOTAL |
|---|---|---|---|---|---|---|---|---|---|
| ALBUQUERQUE | 60.00 | 0.0 | 0.0 | 6.80E-11 | 5.28E-13 | 1.08E-12 | 6.44E-09 | 8.20E-04 | 8.20E-04 |
| BIBO | -2.00 | 3.00 | 0.0 | 2.79E-08 | 2.17E-10 | 4.42E-10 | 2.65E-06 | 1.42E-01 | 1.42E-01 |
| BLUEWATER | -60.00 | 30.00 | 0.0 | 9.90E-11 | 7.68E-13 | 1.57E-12 | 9.37E-09 | 8.38E-04 | 8.38E-04 |
| BELEN | 50.00 | -40.00 | 0.0 | 5.33E-10 | 4.13E-12 | 8.42E-12 | 5.04E-08 | 3.30E-03 | 3.30E-03 |
| CASA BLANCA | -10.00 | -10.00 | 0.0 | 9.82E-09 | 7.62E-11 | 1.55E-10 | 9.29E-07 | 3.37E-02 | 3.37E-02 |
| CUBERO | -16.00 | -10.00 | 0.0 | 4.40E-09 | 3.41E-11 | 6.96E-11 | 4.16E-07 | 1.91E-02 | 1.91E-02 |
| GRANTS- MILLAN | -40.00 | 0.0 | 0.0 | 1.28E-10 | 9.94E-13 | 2.03E-12 | 1.21E-08 | 1.52E-03 | 1.52E-03 |
| JACKPILE-HOUSING | 0.0 | -0.20 | 0.0 | 2.50E-07 | 1.94E-09 | 3.95E-09 | 2.37E-05 | 1.69E-01 | 1.69E-01 |
| LAGUNA AND ENCINAL | -5.00 | 10.00 | 0.0 | 8.96E-09 | 6.95E-11 | 1.42E-10 | 8.48E-07 | 1.03E-01 | 1.03E-01 |
| LOS LUNAS | 60.00 | -30.00 | 0.0 | 2.28E-10 | 1.77E-12 | 3.61E-12 | 2.16E-08 | 1.66E-03 | 1.66E-03 |
| MESITA | 3.00 | -12.00 | 0.0 | 7.86E-08 | 6.10E-10 | 1.24E-09 | 7.44E-06 | 1.30E-01 | 1.30E-01 |
| MONITOR AT DUMP F | 2.70 | 0.0 | 20.00 | 2.12E-07 | 1.64E-09 | 3.35E-09 | 2.00E-05 | 1.66E-01 | 1.66E-01 |
| MONITOR AT WELL 4 | -0.70 | 2.30 | 1.00 | 5.45E-08 | 4.23E-10 | 8.62E-10 | 5.16E-06 | 2.06E-01 | 2.06E-01 |
| MONITOR AT WEST SIDE | -2.00 | 0.70 | 1.00 | 1.43E-07 | 1.11E-09 | 2.25E-09 | 1.35E-05 | 8.87E-02 | 8.88E-02 |
| MONITOR AT MINE VENT | -3.30 | -2.20 | 20.00 | 8.91E-08 | 6.91E-10 | 1.41E-09 | 8.43E-06 | 1.21E-01 | 1.21E-01 |
| MOQUINO | -1.50 | 5.00 | 0.0 | 2.92E-08 | 2.27E-10 | 4.62E-10 | 2.76E-06 | 2.44E-01 | 2.44E-01 |
| PAGUATE | 3.00 | 1.00 | 0.0 | 9.10E-08 | 7.06E-10 | 1.44E-09 | 8.61E-06 | 1.12E-01 | 1.12E-01 |
| SEAMA | -14.00 | -10.00 | 0.0 | 5.81E-09 | 4.51E-11 | 9.19E-11 | 5.50E-07 | 2.31E-02 | 2.31E-02 |
| SAN FIDEL | -25.00 | 0.0 | 0.0 | 3.00E-10 | 2.33E-12 | 4.75E-12 | 2.84E-08 | 3.20E-03 | 3.20E-03 |
| SAN MATEO | -20.00 | 30.00 | 0.0 | 1.29E-09 | 9.99E-12 | 2.04E-11 | 1.22E-07 | 1.67E-02 | 1.67E-02 |
| SABOYETA | 0.0 | 10.00 | 0.0 | 1.18E-08 | 9.15E-11 | 1.87E-10 | 1.12E-06 | 8.87E-02 | 8.87E-02 |
| RANGE NORTH | 0.0 | 5.00 | 0.0 | 3.83E-08 | 2.97E-10 | 6.06E-10 | 3.63E-06 | 2.70E-01 | 2.70E-01 |
| RANGE EAST | -15.00 | 0.0 | 0.0 | 7.91E-10 | 6.13E-12 | 1.25E-11 | 7.48E-08 | 7.07E-03 | 7.07E-03 |
| RANGE WEST | -5.00 | 0.0 | 0.0 | 7.53E-09 | 5.84E-11 | 1.19E-10 | 7.13E-07 | 3.59E-02 | 3.59E-02 |
| RANGE SOUTH | 0.0 | -10.00 | 0.0 | 5.25E-08 | 4.07E-10 | 8.30E-10 | 4.97E-06 | 7.07E-02 | 7.07E-02 |

Table D.23. External Dose Commitments (mrem/yr) to Red Marrow from Cloud Submersion

| IDENTIFICATION | X(KM) | Y(KM) | Z(M) | U238 | U234 | TH230 | RA226 | PB210-RN222 | TOTAL |
|---|---|---|---|---|---|---|---|---|---|
| ALBUQUERQUE | 60.00 | 0.0 | 0.0 | 9.51E-11 | 1.35E-12 | 2.47E-12 | 7.13E-09 | 9.07E-04 | 9.07E-04 |
| BIBO | -2.00 | 3.00 | 0.0 | 3.91E-08 | 5.56E-10 | 1.02E-09 | 2.93E-06 | 1.59E-01 | 1.59E-01 |
| BLUEWATER | -60.00 | 30.00 | 0.0 | 1.38E-10 | 1.97E-12 | 3.60E-12 | 1.04E-08 | 9.27E-04 | 9.27E-04 |
| BELEN | 50.00 | -40.00 | 0.0 | 7.45E-10 | 1.06E-11 | 1.94E-11 | 5.59E-08 | 3.65E-03 | 3.65E-03 |
| CASA BLANCA | -10.00 | -10.00 | 0.0 | 1.37E-08 | 1.95E-10 | 3.57E-10 | 1.03E-06 | 3.73E-02 | 3.73E-02 |
| CUBERO | -16.00 | -10.00 | 0.0 | 6.15E-09 | 8.74E-11 | 1.60E-10 | 4.61E-07 | 2.12E-02 | 2.12E-02 |
| GRANTS- MILLAN | -40.00 | 0.0 | 0.0 | 1.79E-10 | 2.55E-12 | 4.66E-12 | 1.34E-08 | 1.68E-03 | 1.68E-03 |
| JACKPILE-HOUSING | 0.0 | -0.20 | 0.0 | 3.49E-07 | 4.97E-09 | 9.09E-09 | 2.62E-05 | 1.94E-01 | 1.94E-01 |
| LAGUNA AND ENCINAL | -5.00 | 10.00 | 0.0 | 1.25E-08 | 1.78E-10 | 3.26E-10 | 9.39E-07 | 1.14E-01 | 1.14E-01 |
| LOS LUNAS | 60.00 | -30.00 | 0.0 | 3.19E-10 | 4.54E-12 | 8.31E-12 | 2.40E-08 | 1.84E-03 | 1.84E-03 |
| MESITA | 3.00 | -12.00 | 0.0 | 1.10E-07 | 1.56E-09 | 2.86E-09 | 8.25E-06 | 1.44E-01 | 1.44E-01 |
| MONITOR AT DUMP F | 2.70 | 0.0 | 20.00 | 2.96E-07 | 4.21E-09 | 7.70E-09 | 2.22E-05 | 1.89E-01 | 1.89E-01 |
| MONITOR AT WELL 4 | -0.70 | 2.30 | 1.00 | 7.62E-08 | 1.08E-09 | 1.98E-09 | 5.71E-06 | 2.32E-01 | 2.32E-01 |
| MONITOR AT WEST SIDE | -2.00 | 0.70 | 1.00 | 1.99E-07 | 2.83E-09 | 5.19E-09 | 1.50E-05 | 1.02E-01 | 1.02E-01 |
| MONITOR AT MINE VENT | -3.30 | -2.20 | 20.00 | 1.25E-07 | 1.77E-09 | 3.24E-09 | 9.35E-06 | 1.36E-01 | 1.36E-01 |
| MOQUINO | -1.50 | 5.00 | 0.0 | 4.08E-08 | 5.81E-10 | 1.06E-09 | 3.06E-06 | 2.72E-01 | 2.72E-01 |
| PAGUATE | 3.00 | 1.00 | 0.0 | 1.27E-07 | 1.81E-09 | 3.31E-09 | 9.54E-06 | 1.27E-01 | 1.27E-01 |
| SEAMA | -14.00 | -10.00 | 0.0 | 8.12E-09 | 1.15E-10 | 2.11E-10 | 6.09E-07 | 2.56E-02 | 2.56E-02 |
| SAN FIDEL | -25.00 | 0.0 | 0.0 | 4.20E-10 | 5.97E-12 | 1.09E-11 | 3.15E-08 | 3.55E-03 | 3.55E-03 |
| SAN MATEO | -20.00 | 30.00 | 0.0 | 1.80E-09 | 2.56E-11 | 4.68E-11 | 1.35E-07 | 1.85E-02 | 1.85E-02 |
| SABOYETA | 0.0 | 10.00 | 0.0 | 1.65E-08 | 2.34E-10 | 4.29E-10 | 1.24E-06 | 9.86E-02 | 9.86E-02 |
| RANGE NORTH | 0.0 | 5.00 | 0.0 | 5.36E-08 | 7.62E-10 | 1.39E-09 | 4.02E-06 | 3.02E-01 | 3.02E-01 |
| RANGE EAST | -15.00 | 0.0 | 0.0 | 1.11E-09 | 1.57E-11 | 2.88E-11 | 8.29E-08 | 7.84E-03 | 7.84E-03 |
| RANGE WEST | -5.00 | 0.0 | 0.0 | 1.05E-08 | 1.50E-10 | 2.74E-10 | 7.90E-07 | 4.01E-02 | 4.01E-02 |
| RANGE SOUTH | 0.0 | -10.00 | 0.0 | 7.34E-08 | 1.04E-09 | 1.91E-09 | 5.51E-06 | 7.85E-02 | 7.85E-02 |

Table D.24. External Dose Commitments (mrem/yr) to Skeleton from Cloud Submersion

| IDENTIFICATION | X(KM) | Y(KM) | Z(M) | U238 | U234 | TH230 | RA226 | PB210-RN222 | TOTAL |
|---|---|---|---|---|---|---|---|---|---|
| ALBUQUERQUE | 60.00 | 0.0 | 0.0 | 1.04E-10 | 1.51E-12 | 2.72E-12 | 7.67E-09 | 9.75E-04 | 9.75E-04 |
| BIBO | -2.00 | 3.00 | 0.0 | 4.27E-08 | 6.19E-10 | 1.12E-09 | 3.15E-06 | 1.71E-01 | 1.71E-01 |
| BLUEWATER | -60.00 | 30.00 | 0.0 | 1.51E-10 | 2.19E-12 | 3.96E-12 | 1.12E-08 | 9.97E-04 | 9.97E-04 |
| BELEN | 50.00 | -40.00 | 0.0 | 8.14E-10 | 1.18E-11 | 2.13E-11 | 6.01E-08 | 3.93E-03 | 3.93E-03 |
| CASA BLANCA | -10.00 | -10.00 | 0.0 | 1.50E-08 | 2.17E-10 | 3.93E-10 | 1.11E-06 | 4.01E-02 | 4.01E-02 |
| CUBERO | -16.00 | -10.00 | 0.0 | 6.72E-09 | 9.74E-11 | 1.76E-10 | 4.96E-07 | 2.27E-02 | 2.27E-02 |
| GRANTS- MILLAN | -40.00 | 0.0 | 0.0 | 1.96E-10 | 2.84E-12 | 5.12E-12 | 1.44E-08 | 1.81E-03 | 1.81E-03 |
| JACKPILE-HOUSING | 0.0 | -0.20 | 0.0 | 3.82E-07 | 5.53E-09 | 1.00E-08 | 2.82E-05 | 2.09E-01 | 2.09E-01 |
| LAGUNA AND ENCINAL | -5.00 | 10.00 | 0.0 | 1.37E-08 | 1.98E-10 | 3.58E-10 | 1.01E-06 | 1.23E-01 | 1.23E-01 |
| LOS LUNAS | 60.00 | -30.00 | 0.0 | 3.49E-10 | 5.06E-12 | 9.14E-12 | 2.58E-08 | 1.98E-03 | 1.98E-03 |
| MESITA | 3.00 | -12.00 | 0.0 | 1.20E-07 | 1.74E-09 | 3.14E-09 | 8.87E-06 | 1.55E-01 | 1.55E-01 |
| MONITOR AT DUMP F | 2.70 | 0.0 | 20.00 | 3.23E-07 | 4.69E-09 | 8.46E-09 | 2.39E-05 | 2.03E-01 | 2.03E-01 |
| MONITOR AT WELL 4 | -0.70 | 2.30 | 1.00 | 8.32E-08 | 1.21E-09 | 2.18E-09 | 6.14E-06 | 2.49E-01 | 2.49E-01 |
| MONITOR AT WEST SIDE | -2.00 | 0.70 | 1.00 | 2.18E-07 | 3.16E-09 | 5.70E-09 | 1.61E-05 | 1.09E-01 | 1.09E-01 |
| MONITOR AT MINE VENT | -3.30 | -2.20 | 20.00 | 1.36E-07 | 1.97E-09 | 3.56E-09 | 1.00E-05 | 1.46E-01 | 1.46E-01 |
| MOQUINO | -1.50 | 5.00 | 0.0 | 4.46E-08 | 6.47E-10 | 1.17E-09 | 3.29E-06 | 2.93E-01 | 2.93E-01 |
| PAGUATE | 3.00 | 1.00 | 0.0 | 1.39E-07 | 2.01E-09 | 3.64E-09 | 1.03E-05 | 1.37E-01 | 1.37E-01 |
| SEAMA | -14.00 | -10.00 | 0.0 | 8.87E-09 | 1.29E-10 | 2.32E-10 | 6.55E-07 | 2.75E-02 | 2.75E-02 |
| SAN FIDEL | -25.00 | 0.0 | 0.0 | 4.58E-10 | 6.64E-12 | 1.20E-11 | 3.38E-08 | 3.81E-03 | 3.81E-03 |
| SAN MATEO | -20.00 | 30.00 | 0.0 | 1.97E-09 | 2.85E-11 | 5.15E-11 | 1.45E-07 | 1.98E-02 | 1.98E-02 |
| SABOYETA | 0.0 | 10.00 | 0.0 | 1.80E-08 | 2.61E-10 | 4.72E-10 | 1.33E-06 | 1.06E-01 | 1.06E-01 |
| RANGE NORTH | 0.0 | 5.00 | 0.0 | 5.85E-08 | 8.49E-10 | 1.53E-09 | 4.32E-06 | 3.24E-01 | 3.24E-01 |
| RANGE EAST | -15.00 | 0.0 | 0.0 | 1.21E-09 | 1.75E-11 | 3.16E-11 | 8.91E-08 | 8.43E-03 | 8.43E-03 |
| RANGE WEST | -5.00 | 0.0 | 0.0 | 1.15E-08 | 1.67E-10 | 3.01E-10 | 8.49E-07 | 4.31E-02 | 4.31E-02 |
| RANGE SOUTH | 0.0 | -10.00 | 0.0 | 8.02E-08 | 1.16E-09 | 2.10E-09 | 5.92E-06 | 8.44E-02 | 8.44E-02 |

## D.3.3 Ingestion Dose Commitments

Table D.25. Dose Commitments (mrem/yr)
to Whole Body from Ingestion

| IDENTIFICATION | PATHWAY | U238 | U234 | TH230 | RA226 | PB210 | PO210 | TOTAL |
|---|---|---|---|---|---|---|---|---|
| BIBO | MEAT | 1.68E-04 | 1.91E-04 | 1.74E-04 | 2.00E-01 | 4.03E-03 | 4.66E-02 | 2.51E-01 |
| CASA BLANCA | MEAT | 3.48E-05 | 3.96E-05 | 3.60E-05 | 4.14E-02 | 9.28E-04 | 1.03E-02 | 5.27E-02 |
| CUBERO | MEAT | 1.24E-05 | 1.41E-05 | 1.29E-05 | 1.48E-02 | 3.72E-04 | 3.93E-03 | 1.91E-02 |
| LAGUNA AND ENCINAL | MEAT | 2.54E-05 | 2.90E-05 | 2.64E-05 | 3.03E-02 | 8.26E-04 | 8.43E-03 | 3.96E-02 |
| MESITA | MEAT | 3.17E-04 | 3.61E-04 | 3.29E-04 | 3.78E-01 | 7.85E-03 | 9.00E-02 | 4.77E-01 |
| MOQUINO | MEAT | 1.29E-04 | 1.47E-04 | 1.34E-04 | 1.54E-01 | 3.25E-03 | 3.69E-02 | 1.95E-01 |
| PAGUATE | MEAT | 7.50E-04 | 8.54E-04 | 7.77E-04 | 8.95E-01 | 1.77E-02 | 2.06E-01 | 1.12E+00 |
| SEAMA | MEAT | 1.77E-05 | 2.01E-05 | 1.83E-05 | 2.11E-02 | 5.06E-04 | 5.45E-03 | 2.71E-02 |
| SAN FIDEL | MEAT | 4.56E-07 | 5.20E-07 | 4.74E-07 | 5.42E-04 | 2.73E-05 | 2.27E-04 | 7.98E-04 |
| SAN MATEO | MEAT | 1.97E-06 | 2.25E-06 | 2.05E-06 | 2.35E-03 | 1.76E-04 | 1.32E-03 | 3.85E-03 |
| SABOYETA | MEAT | 3.46E-05 | 3.94E-05 | 3.59E-05 | 4.12E-02 | 9.79E-04 | 1.06E-02 | 5.29E-02 |
| RANGE NORTH | MEAT | 1.67E-04 | 1.91E-04 | 1.74E-04 | 2.00E-01 | 4.15E-03 | 4.75E-02 | 2.52E-01 |
| RANGE EAST | MEAT | 1.67E-06 | 1.90E-06 | 1.73E-06 | 1.99E-03 | 6.13E-05 | 5.99E-04 | 2.65E-03 |
| RANGE WEST | MEAT | 3.61E-05 | 4.11E-05 | 3.74E-05 | 4.30E-02 | 8.85E-04 | 1.02E-02 | 5.42E-02 |
| RANGE SOUTH | MEAT | 2.44E-04 | 2.78E-04 | 2.53E-04 | 2.91E-01 | 5.91E-03 | 6.83E-02 | 3.66E-01 |

Table D.26. Dose Commitments (mrem/yr)
to Bone from Ingestion

| IDENTIFICATION | PATHWAY | U238 | U234 | TH230 | RA226 | PB210 | PO210 | TOTAL |
|---|---|---|---|---|---|---|---|---|
| BIBO | MEAT | 2.83E-03 | 3.09E-03 | 6.28E-03 | 2.00E+00 | 1.26E-01 | 1.90E-01 | 2.33E+00 |
| CASA BLANCA | MEAT | 5.87E-04 | 6.40E-04 | 1.30E-03 | 4.14E-01 | 2.90E-02 | 4.19E-02 | 4.87E-01 |
| CUBERO | MEAT | 2.10E-04 | 2.29E-04 | 4.65E-04 | 1.48E-01 | 1.16E-02 | 1.60E-02 | 1.76E-01 |
| LAGUNA AND ENCINAL | MEAT | 4.30E-04 | 4.69E-04 | 9.54E-04 | 3.03E-01 | 2.58E-02 | 3.43E-02 | 3.65E-01 |
| MESITA | MEAT | 5.35E-03 | 5.84E-03 | 1.19E-02 | 3.78E+00 | 2.45E-01 | 3.67E-01 | 4.41E+00 |
| MOQUINO | MEAT | 2.18E-03 | 2.38E-03 | 4.84E-03 | 1.54E+00 | 1.02E-01 | 1.50E-01 | 1.80E+00 |
| PAGUATE | MEAT | 1.27E-02 | 1.38E-02 | 2.81E-02 | 8.95E+00 | 5.51E-01 | 8.38E-01 | 1.04E+01 |
| SEAMA | MEAT | 2.99E-04 | 3.26E-04 | 6.63E-04 | 2.11E-01 | 1.58E-02 | 2.22E-02 | 2.50E-01 |
| SAN FIDEL | MEAT | 7.70E-06 | 8.40E-06 | 1.71E-05 | 5.42E-03 | 8.52E-04 | 9.25E-04 | 7.23E-03 |
| SAN MATEO | MEAT | 3.33E-05 | 3.64E-05 | 7.41E-05 | 2.35E-02 | 5.49E-03 | 5.38E-03 | 3.45E-02 |
| SABOYETA | MEAT | 5.84E-04 | 6.37E-04 | 1.30E-03 | 4.12E-01 | 3.06E-02 | 4.32E-02 | 4.88E-01 |
| RANGE NORTH | MEAT | 2.83E-03 | 3.08E-03 | 6.28E-03 | 2.00E+00 | 1.30E-01 | 1.93E-01 | 2.33E+00 |
| RANGE EAST | MEAT | 2.82E-05 | 3.07E-05 | 6.26E-05 | 1.99E-02 | 1.91E-03 | 2.44E-03 | 2.43E-02 |
| RANGE WEST | MEAT | 6.10E-04 | 6.65E-04 | 1.35E-03 | 4.30E-01 | 2.76E-02 | 4.14E-02 | 5.02E-01 |
| RANGE SOUTH | MEAT | 4.12E-03 | 4.49E-03 | 9.14E-03 | 2.91E+00 | 1.85E-01 | 2.78E-01 | 3.39E+00 |

Table D.27. Dose Commitments (mrem/yr) to Kidney from Ingestion

| IDENTIFICATION | PATHWAY | U238 | U234 | TH230 | RA226 | PB210 | PO210 | TOTAL |
|---|---|---|---|---|---|---|---|---|
| BIBO | MEAT | 6.46E-04 | 7.36E-04 | 1.62E-03 | 6.74E-03 | 1.04E-01 | 1.40E+00 | 1.51E+00 |
| CASA BLANCA | MEAT | 1.34E-04 | 1.52E-04 | 3.36E-04 | 1.40E-03 | 2.40E-02 | 3.09E-01 | 3.35E-01 |
| CUBERO | MEAT | 4.78E-05 | 5.45E-05 | 1.20E-04 | 4.98E-04 | 9.62E-03 | 1.18E-01 | 1.28E-01 |
| LAGUNA AND ENCINAL | MEAT | 9.80E-05 | 1.12E-04 | 2.46E-04 | 1.02E-03 | 2.14E-02 | 2.53E-01 | 2.76E-01 |
| MESITA | MEAT | 1.22E-03 | 1.39E-03 | 3.06E-03 | 1.27E-02 | 2.03E-01 | 2.71E+00 | 2.93E+00 |
| MOQUINO | MEAT | 4.97E-04 | 5.67E-04 | 1.25E-03 | 5.19E-03 | 8.42E-02 | 1.11E+00 | 1.20E+00 |
| PAGUATE | MEAT | 2.89E-03 | 3.29E-03 | 7.24E-03 | 3.01E-02 | 4.57E-01 | 6.18E+00 | 6.68E+00 |
| SEAMA | MEAT | 6.81E-05 | 7.76E-05 | 1.71E-04 | 7.10E-04 | 1.31E-02 | 1.64E-01 | 1.78E-01 |
| SAN FIDEL | MEAT | 1.76E-06 | 2.00E-06 | 4.42E-06 | 1.83E-05 | 7.06E-04 | 6.82E-03 | 7.56E-03 |
| SAN MATEO | MEAT | 7.60E-06 | 8.66E-06 | 1.91E-05 | 7.91E-05 | 4.55E-03 | 3.97E-02 | 4.44E-02 |
| SABOYETA | MEAT | 1.33E-04 | 1.52E-04 | 3.35E-04 | 1.39E-03 | 2.53E-02 | 3.19E-01 | 3.46E-01 |
| RANGE NORTH | MEAT | 6.45E-04 | 7.35E-04 | 1.62E-03 | 6.73E-03 | 1.07E-01 | 1.43E+00 | 1.54E+00 |
| RANGE EAST | MEAT | 6.43E-06 | 7.32E-06 | 1.61E-05 | 6.69E-05 | 1.59E-03 | 1.80E-02 | 1.97E-02 |
| RANGE WEST | MEAT | 1.39E-04 | 1.58E-04 | 3.49E-04 | 1.45E-03 | 2.29E-02 | 3.06E-01 | 3.31E-01 |
| RANGE SOUTH | MEAT | 9.39E-04 | 1.07E-03 | 2.36E-03 | 9.79E-03 | 1.53E-01 | 2.05E+00 | 2.22E+00 |

Table D.28. Dose Commitments (mrem/yr) to Liver from Ingestion

| IDENTIFICATION | PATHWAY | U238 | U234 | TH230 | RA226 | PB210 | PO210 | TOTAL |
|---|---|---|---|---|---|---|---|---|
| BIBO | MEAT | 0.0 | 0.0 | 3.58E-04 | 2.38E-04 | 3.19E-02 | 4.18E-01 | 4.50E-01 |
| CASA BLANCA | MEAT | 0.0 | 0.0 | 7.42E-05 | 4.92E-05 | 7.35E-03 | 9.22E-02 | 9.96E-02 |
| CUBERO | MEAT | 0.0 | 0.0 | 2.65E-05 | 1.76E-05 | 2.95E-03 | 3.52E-02 | 3.82E-02 |
| LAGUNA AND ENCINAL | MEAT | 0.0 | 0.0 | 5.43E-05 | 3.60E-05 | 6.54E-03 | 7.55E-02 | 8.22E-02 |
| MESITA | MEAT | 0.0 | 0.0 | 6.77E-04 | 4.49E-04 | 6.22E-02 | 8.07E-01 | 8.70E-01 |
| MOQUINO | MEAT | 0.0 | 0.0 | 2.76E-04 | 1.83E-04 | 2.58E-02 | 3.31E-01 | 3.57E-01 |
| PAGUATE | MEAT | 0.0 | 0.0 | 1.60E-03 | 1.06E-03 | 1.40E-01 | 1.84E+00 | 1.99E+00 |
| SEAMA | MEAT | 0.0 | 0.0 | 3.78E-05 | 2.50E-05 | 4.00E-03 | 4.88E-02 | 5.29E-02 |
| SAN FIDEL | MEAT | 0.0 | 0.0 | 9.76E-07 | 6.45E-07 | 2.16E-04 | 2.03E-03 | 2.25E-03 |
| SAN MATEO | MEAT | 0.0 | 0.0 | 4.22E-06 | 2.79E-06 | 1.39E-03 | 1.18E-02 | 1.32E-02 |
| SABOYETA | MEAT | 0.0 | 0.0 | 7.39E-05 | 4.90E-05 | 7.75E-03 | 9.50E-02 | 1.03E-01 |
| RANGE NORTH | MEAT | 0.0 | 0.0 | 3.57E-04 | 2.37E-04 | 3.29E-02 | 4.26E-01 | 4.59E-01 |
| RANGE EAST | MEAT | 0.0 | 0.0 | 3.57E-06 | 2.36E-06 | 4.86E-04 | 5.37E-03 | 5.86E-03 |
| RANGE WEST | MEAT | 0.0 | 0.0 | 7.70E-05 | 5.12E-05 | 7.01E-03 | 9.11E-02 | 9.82E-02 |
| RANGE SOUTH | MEAT | 0.0 | 0.0 | 5.20E-04 | 3.46E-04 | 4.68E-02 | 6.12E-01 | 6.60E-01 |

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